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DISSERTATION

Fundamental Capability Portfolio Management

A Study of Developing Systems with Implications for Army Research and Development Strategy

Scott Hiromoto

This document was submitted as a dissertation in January 2013 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Brian G. Chow (Chair), Elliot Axelband, and Fred Timson.

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Summary

Over the past years, the United States Army has faced an increasingly austere budgetary environment of unknown duration. At the same time, in the future the Army must prepare for a more diverse, burdensome and uncertain strategic environment, from conventional warfare to counter-insurgency. Anticipating these constraints, in 2006 the Department of Defense (DoD) mandated the use of capability portfolio management in acquisitions, to ensure that an efficient mix of systems is being developed and fielded within strict budgetary limitations. However, a lack of research in two important areas is constraining the ability of the Army to perform effective portfolio analyses. First, there is limited research to help the Army perform specific portfolio analysis and assessment of this kind. Second, for individual systems within a portfolio, a body of research has documented the extent and causes of cost growth, schedule delay, and cancelation in ‘major weapon systems’, but relatively less attention has been paid to the smaller, less expensive systems that actually make up the majority of the Army’s budget.

A growing literature has begun to establish a framework for portfolio analyses involving military systems. These studies have often focused on project selection either within a capability requirement area, which groups systems within a very broad category, or across such broad categorical areas. A capability requirement area actually contains multiple systems serving very different specific functions at a more fundamental, basic level. For example, ‘Lethality’ is one traditional capability requirement area defined by the Army as the ability to destroy or neutralize adversaries. The lethality requirement needs to be accomplished in a myriad of different ways depending on the situation by utilizing a variety of weapons, such as small arms, missiles, mortars, and artillery. Therefore, prior to the consideration of gaps within the overall lethality capability area, one must first assess whether investment in development efforts will result in the right mix of systems to satisfy each of the specific fundamental capabilities. One such example is the small arms fundamental capability - the systems that provide this capability compose the small arms fundamental capability portfolio. The study of fundamental capabilities and their fundamental capability portfolios are the focus of this dissertation.

A portfolio can contain both ‘major weapon systems’ and less expensive systems. ‘Major weapon systems’ are estimated to require eventual research, development, test, and evaluation (RDT&E) expenditures of more than $300 million, or eventual procurement expenditures of over $1.8 billion. Major weapon systems have been the subject of extensive research in the past. However, since less-expensive systems make up 80% of the Army’s acquisition budget, they should not be under-assessed. Indeed, in many cases less expensive, smaller systems will make up the majority or totality

of systems within a fundamental capability portfolio. Further, past research has focused on individual systems as standalone development projects and has not adequately considered the interdependency amongst systems in the overall development portfolio. Major weapon systems, due to their high cost, are often the only development effort aimed at filling a particular capability gap. On the other hand, amongst smaller systems there are often close substitutes or even directly competing systems - developed by a rival company or mandated by the Army itself– that could all fulfill a capability gap. As a result, in a portfolio management context, there is a question as to whether the development of closely related systems is wasteful redundancy on the one hand, or useful insurance against failure of some development programs on the other. The development paths of major weapon systems may also diverge from those of smaller systems. While major weapon systems are often developed to counter perceived future threats, which may give developers some scheduling leeway, smaller programs are often initiated to counter imminent, recently revealed threats, such as the use of novel IEDs by insurgents. For such systems, rapid development and fielding is of urgent importance given an environment in which casualties, rather than dollars, are often an influential driving factor in deciding whether to enter or continue an armed conflict or war.

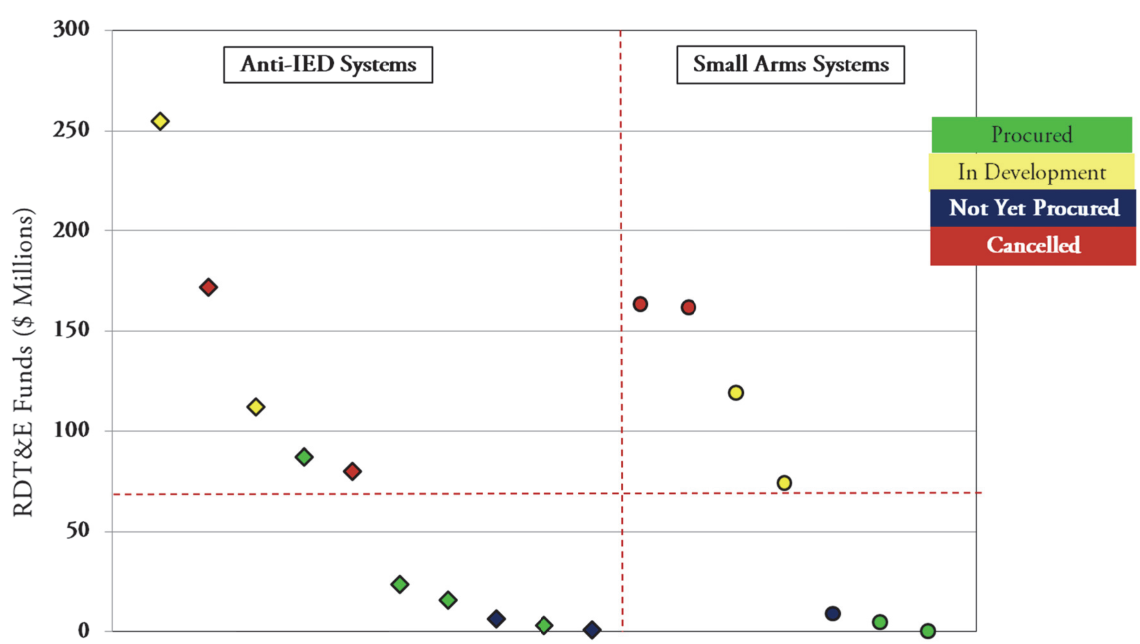
These observations motivate the performance of two 'fundamental' portfolio reviews within this dissertation that focus, respectively, on anti-improvised explosive device (anti-IED) systems and small arms. A fundamental capability portfolio review builds 'from the ground up' to assess how well the aggregations of individual under-development Army systems provide for each fundamental capability. Especially when the Army is under budgetary constraint, fundamental capability analysis allows for an understanding of complementarity and redundancy amongst developing systems so that one can select the most cost-effective portfolio of projects to fund. In turn, from individual fundamental capability portfolio reviews, one can aggregate findings and select projects that will most effectively satisfy a capability requirement area within budget. Aggregating at a higher level still amongst these capability requirement areas can result in an overall strategy for the total portfolio of developing Army systems.

The two fundamental capability portfolios reviewed herein were selected because of the importance of both groups of systems. Small arms contribute significantly to the lethality capability area, while anti-IED systems are, in the current anti-insurgency environment, a key aspect of the force protection capability area. The dissertation assesses seven small arms systems and ten anti-IED systems that were under development in fiscal year (FY) 2006, tracking each system from inception to current state, and analyzes how each system contributes to the respective fundamental capability area in question. The systems under study represent all of the small arms and anti-IED development programs that appear in the FY 2006 Army (RDT&E) records. RDT&E data, which tracks expenditures related to system development, are available for most systems from 1998 to expected future expenditures as far forward as 2015, resulting in seventeen years of available data. Systems under development in 2006 are at the midpoint between these two dates. Each portfolio review determines whether development projects and expenditure of development funds resulted in adequate fulfillment of capability gaps within the fundamental capability that applies.

A case study methodology was utilized to collect data related to development cost, development schedule, and expected capability provision of each of the systems under development. Each of the systems is considered in terms of its specific function within the fundamental capability portfolio, and in relationship to 'legacy systems' (if any), which are defined as already fielded systems that new, developing systems are meant to replace. Development outcomes of the systems indicate the overall success of the Army in meeting capability requirements during the chosen time frame.

In aggregate, the seventeen small arms and anti-IED systems that were analyzed can generally be split into two development cost levels. The vertical red dotted line in **Figure S.1**separates anti-IED systems on the left from small arms systems at the right of the plot. For both groups, the systems are ordered by most expensive system to least expensive in terms of total RDT&E funds, which are used to mature systems until they are ready to be manufactured and fielded. Nine relatively high-cost systems are above the horizontal red dotted line in **Figure S.1**, and all cost over $70 million, each. On the other hand, a group of eight relatively inexpensive systems lies below the red dotted line in the figure, and none cost over $25 million to develop.

Figure S.1 - Anti-IED and Small Arms Systems Costs and Outcomes



The more expensive group of systems tended to be novel systems, built from the ground up, and were relatively more ambitious in terms of providing new, unique capabilities. The less expensive group of systems were generally based on legacy systems, and more often than not were modifications of existing military systems, or commercial systems modified for military use.

Development outcomes suggest an inefficient use of research funds in terms of both the types of systems that were either canceled or never fielded as well as the dollar values associated with those systems. Over the course of the study period, four systems were terminated before development was complete, as indicated by the four red points in **Figure S.1**. All of these systems were from the relatively higher expense, more ambitious development group. In contrast, three systems largely completed development or were ready to be fielded, but have not yet been selected for procurement. All of these systems were from the less expensive group of development projects (blue points in **Figure S.1**). Six development projects resulted in procured systems that will be useful in the field (green points). Of these, only one was from the more expensive group of systems and was one of the least expensive systems to develop within that group. The other five procured systems result from lower-cost development efforts. The remaining four systems, still under development, belong to the group of higher development cost systems (yellow points).

On average, systems that are currently still in development have been in that state for just over twelve and a half years.

While four projects were canceled out of a total of seventeen, terminations represented nearly 45% of total development dollars accounted for in this study. If this finding among 17 systems is confirmed in future studies, the large percentage of funds lost to canceled program would be a serious concern, especially in the current (and indefinite) budget-constrained environment.

Cancelations and protracted development of systems often led to uneven coverage of capability gaps within fundamental capability portfolios.

The ten systems under development by the Army within the anti-IED fundamental capability portfolio fall into one of two categories: mine detection or mine neutralization. Development successes amongst mine neutralization systems have resulted in a dramatic decrease in the number of remotely detonated, wireless IEDs used against troops in Iraq and Afghanistan. In 2005, ninety percent of IED attacks in Iraq used remotely detonated, wireless IEDs. As of 2009, that number had dropped to twenty percent nationwide. A philosophy of quick-turnaround modification of preexisting military technology with rapid fielding across multiple development efforts was largely responsible for this victory. However, insurgents have adapted to new Army technology by shifting to the use of more primitive IEDs in Iraq and Afghanistan, which are impervious to electronic jamming, and which heighten the need for better mine detection systems as an alternative means of denial. Through the use of commercial systems and the modification of existing military technology, there have been successes in this area. However, the development of systems providing true standoff detection capabilities, that do not expose soldiers to the potential blast radius of IEDs, has been slow to develop or have been terminated.

Turning to the small arms fundamental capability portfolio, as of 2006 the Army had ambitious plans for technological transformation. A myriad of older systems were to be replaced largely by two revolutionary new weapons – the soldier-borne Objective Individual Combat Weapon (OICW) and the crew operated Advanced Crew Served Weapon (ACSW). These two systems, part of a group of seven small arms systems under development, were the cornerstones of the Army's long-term strategic vision. In the end, both systems were canceled. As a result, the portfolio of small arms weapons available to soldiers in the field now looks much the same as it did a decade ago, with few improvements.

Analysis of this sample of seventeen development projects leads to the following findings and recommendations:

Important findings:

Finding one: Less expensive systems are more likely to be successfully developed and fielded than more expensive ones. Within the context of the fundamental capability portfolio, more expensive systems also have the potential to fill larger capability gaps. In the anti-IED portfolio, the Airborne Standoff Mine Detection System (ASTAMIDS) and Ground Standoff Mine Detection System (GSTAMIDS) were two key systems in standoff mine and IED detection. Neither has been fielded to date. Within the small arms fundamental capability portfolio, the fielding of a new air-bursting smart munition promised by the Objective Individual Combat Weapon and Advanced Crew Served Weapon was extensively delayed as a result of the cancelation of both systems, resulting in the lack of an important capability for more than a decade.

Finding two: Technology is commonly salvaged from cancelled programs. Of the seventeen systems reviewed here, four were officially canceled. In each case, some portion of the technology was transferred to another development effort and in most cases resulted in fielding. Cancellation of development programs is therefore not synonymous with total failure.

Recommendations for individual systems:

Within a fundamental capability portfolio, the military should consider the value and urgency of need for a system before establishing multiple or overly ambitious initial requirements for a system, introducing new requirements following the beginning of development, or requiring integration between systems that are concurrently in some stage of development and not yet matured.

Recommendation one: Fielding useful and timely systems should be the goal of development. If development efforts with focused goals succeed in producing fielded systems, improved or new capabilities can be added once lessons-learned from real-world use are incorporated. This would get systems fielded to the troops in a timelier manner and provide a higher probability of success for system development. As an example, the Army fielded various iterations of IED jamming systems quickly to bring a vital capability to the field, without waiting for the systems to be at a perfected level of development.

Recommendation two: Realistic and simple initial requirements are highly desirable. The OICW and ACSW programs were required to be of lighter weight in comparison to legacy systems and at the same time had to fire both conventional ammunition as well as an air-bursting smart munition. In the case of the OICW, the integration of complex electronic components that calculated distance of explosion for the air-bursting munition would have inevitably added weight to the system and were thus directly contradictory to the requirement of weight reduction. As a result, the maturity of technology lagged behind Army guidelines at key development milestones. Given the need to fill capability gaps quickly, it might have made more sense to develop a light carbine for use by individual soldiers, while separately develop an air-bursting capable weapon to be deployed perhaps at the company level, as opposed to being issued to each individual soldier. This solution should be adequate, as an air-bursting capability is likely to be used relatively less frequently in combat than the traditional carbine.

Recommendation three: The use of commercial and government off-the-shelf technology (COTS and GOTS, respectively) – which has already been developed and can be modified for military use - should and currently is being emphasized as a potential source of capabilities, especially in a tight budgetary environment. The Ground Standoff Mine Detection System was characterized by demanding requirements such as avoidance from enemy detection and autonomous navigation that ultimately led to delay and cancellation. On the other hand, the Autonomous Mine Detection System (AMDS) utilizes technology originally developed for GSTAMIDS, which is to be integrated on a GOTS platform. While the capabilities of AMDS are lower than those of GSTAMIDS, development has taken much less time and is more likely to result in a fielded system.

Recommendation four: The Army should refrain from 'requirement creep,' wherein additional requirements are added to a system already undergoing development. The Airborne Standoff Mine Detection System was originally designed to provide standoff mine detection capabilities from the air, and was one of the few in-development systems that could fill that particular gap. However, during ongoing development, requirements were modified to also include enemy target (e.g. vehicle or personnel) acquisition requirements. These changes contributed to significant delays in the development of the system. ASTAMIDS was also developed concurrently with technologically immature UAV platforms that were meant to carry the mine detection system. However, concurrent development meant that some aspects of the final configurations of systems were unknown, complicating integration and increasing development cost. Worse yet, the intended host UAV systems was canceled and replaced by another still in development UAV on several successive occasions. As a result, integration efforts had to begin anew repeatedly, resulting in delay.

Recommendation five: In some of the cases studied here, new components with competing requirements were supposed to be integrated into a single system. However, program managers should balance the need for integration of new systems with the need to field capabilities in a timely manner. In the case of the OICW, several important components of the overall system were still in early stages of development even as integration of those components had to occur in order to remain on schedule. In particular, there were issues with the effectiveness of the blast provided by the 25mm air-bursting munition. If the shape or size of the round itself had to be changed, it would delay development of the main small arm system and potentially violate existing weight reduction requirements. On the other hand, if changes to the small arm could not have been made, it would mean requiring increased burst for the 25mm munition at a fixed size and weight. Technical issues such as these are likely to increase the risk of delay and cancelation.

Recommendations for portfolio management:

Recommendation one: Given the inevitability of failure in some development programs, effective portfolio management necessitates the explicit development of realistic alternative plans that initiate immediately in cases where no fielded systems seem likely to arise from current development efforts. In a tight budgetary environment, this may mean that development of an ambitious system is halted so as to fund systems providing a lower capability but a higher likelihood of near-term fielding.

Recommendation two: In choosing systems to develop, the Army should explicitly consider time to fielding and the risk of program failure of each system, and should attempt to fulfill capability gaps sooner rather than later. The cancellation of the OICW and ACSW in the small arms portfolio and ASTAMIDS and GSTAMIDS in the anti-IED portfolio left significant gaps in each fundamental capability portfolio. In considering higher-capability, higher-risk systems like these, the Army should not only assess the expected capability of the system, but should also consider the expected length of development of the system and likelihood that the development program will fail to meet performance or cost objectives. By engaging in these calculations, it may be that the Army opts to develop systems that provide fewer capabilities but are more likely to be developed quickly and successfully.

Recommendation three: Substitutes do exist between developing systems, but a safety margin is necessary in the fundamental capability portfolio to guard against inevitable challenges such as performance shortfall, schedule delay or cancelation of programs. As a result, policymakers should make careful considerations before cutting 'redundant' programs. In the small arms portfolio, the Lightweight Medium Machine Gun and M240L are similar machine guns developed relatively cheaply, at a cost to the military of $250,000 and $4.9 million, respectively. Bringing such systems to a 'ready to be fielded' state is inexpensive compared to the overall procurement, operating and maintenance budgets. Meanwhile, providing a safety margin in the overall portfolio is likely to be strategically important and economical, since it results in a higher likelihood of fulfilling a capability gap and/or lower procurement and operating and maintenance costs in the future if the most cost-effective system amongst a group can ultimately be selected for fielding.

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Finally, this dissertation is dedicated in memory of Nathan Cohen.

Abbreviations

ACAT	Acquisition Category
ACSW	Advanced Crew Served Weapon
ACTD	Advanced Concept Technology Demonstration
AFP	Amplifying Fluorescent Polymer
AMDS	Autonomous Mine Detection System
ANS	Autonomous Navigation System
ASTAMIDS	Airborne Standoff Mine Detection System
CBRN	Chemical, biological, radiological and nuclear
CDS	Change Detection Server
CDWS	Change Detection Workstation
COE	Common Operating Environment
COTS	Commercial Off-the-Shelf
DoD	Department of Defense
DTIC	Defense Technology Information Center
EDIT	Electromagnetic Wave Detection and Imaging Transceiver
EMD	Engineering and Manufacturing Development
FCS	Future Combat System
FOC	Force Operating Capability
FY	Fiscal Year
GAO	Government Accountability Office

GOTS	Government Off-the-Shelf
GPR	Ground-Penetrating Radar
GSTAMIDS	Ground Standoff Mine Detection System
HEMMS	Hand Emplaced Minefield Marking System
HMDS	Husky Mine Detection System
HSTAMIDS	Handheld Standoff Mine Detection System
IED	Improvised Explosive Devices
JCAAMP	Joint IED Capability Approval and Acquisition Management Process
JEIDDO	Joint Improvised Explosive Device Defeat Organization
JIEDDTF	Joint Improvised Explosive Device Defeat Task Force
LMG	Lightweight Machine Gun
LRIP	Low-Rate Initial Production
LWMMG	Lightweight Medium Machine Gun
MDS	Mine Detection and marking System
MDV	Mine Detection Vehicle
MM - UGV	Multi-Mission Unmanned Ground Vehicle
MPCV	Mine Protected Clearance Vehicle
MULE	Multifunction Utility/Logistics and Equipment
NLOS	Non-Line-of-Sight Launch System
OICW	Objective Individual Combat Weapon
PE	Program Element
RDT&E	Research, Development, Test and Evaluation
RSTA / LA	Reconnaissance, Surveillance, and Target Acquisition / Laser Designation

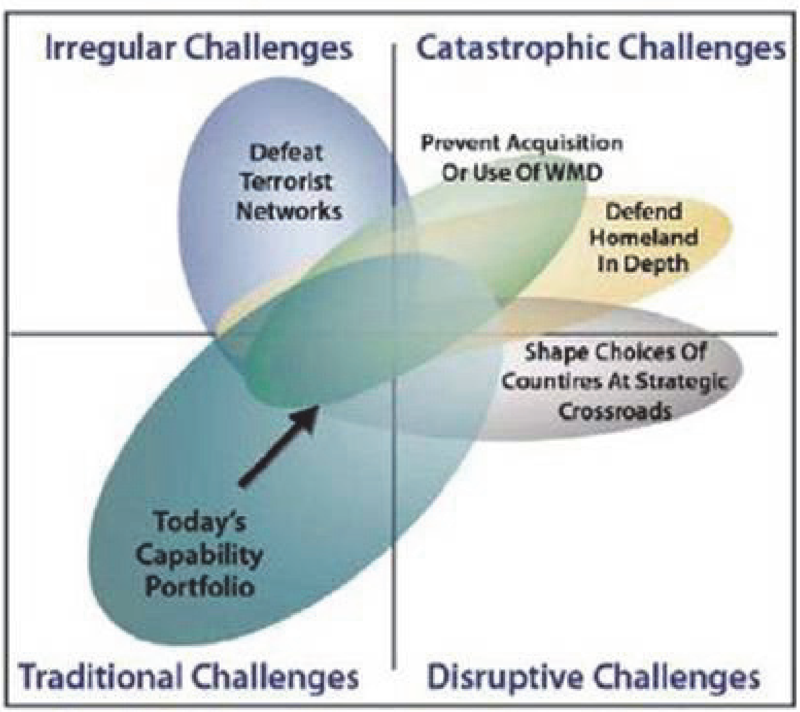
RTBF	Ready-to-be-Fielded
SAR	Synthetic Aperture Radar
SARs	Selected Acquisition Reports
SBIR	Small Business Innovation and Research
STI	Science and Technology Institute
TRL	Technology Readiness Level
TUAV	Tactical Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle

Chapter One - Introduction

In January 2010, Secretary of Defense Robert Gates specifically called for more than $100 billion in cuts to defense spending over the following five years.[1] Deputy Defense Secretary William Lynn specified that one-third of budgetary cuts would come from force structure and modernization - resulting in less funding for the research, development, testing and evaluation and weapon acquisition budgets.[2] Given the long road ahead in recovery from severe recent economic conditions, these cuts will likely continue for the foreseeable future.

While the Army is facing an austere budgetary environment of indefinite duration, it must at the same time contend with an uncertain and difficult strategic environment. According to DoD taxonomy illustrated in **Figure 1.1**, the services must not only contend with traditional challenges (lower left quadrant of the figure), for which the current capability portfolio is most suited.

Figure 1.1 – Future Capability Challenges



Source: Department of Defense Quadrennial Defense Review Report (2006)

[1] Governmentexecutive.com (2010)
[2] 1500 AM Federal News (2010)

They must also prepare for irregular challenges such as terrorism and insurgency (upper left quadrant), prevent catastrophic scenarios such as enemy use of weapons of mass destruction (upper right quadrant), and must control potentially disruptive challenges by guiding countries at strategic crossroads (lower right quadrant).

In recognition of these challenges, in 2001 the DoD moved away from threat-based planning, which focused on known foes and specific scenarios, toward capabilities-based planning. The objective of the move was to prepare for a wider range of future capabilities that adversaries could employ against the United States and evaluate the ability of the military to respond to each of them, rather than to 'over-optimize' the forces for a limited set of threat scenarios.[3]

As wide-ranging challenges increase, the Army faces a difficult tradeoff. On the one hand, it cannot afford to develop an indiscriminately large number of systems. On the other hand, it needs to develop the right types of systems that can be acquired and fielded according to a broader range of defense requirements. Since requirements will change as the result of new conflicts and stability operations in the future, the types of systems selected for development need to be readily applicable to a wide variety of future scenarios or be quickly adaptable to deal with new challenges. The latter is complicated by the fact that it can take many years to fully develop new systems or modify existing systems. Often, the Army cannot afford to wait until new threats actually appear before designing the right systems to confront them.

In such an environment, it is important for the Army to carefully select system development projects. However, in comparison to commercial companies, a Government Accountability Office (GAO) assessment found that the DoD has entered into investment decisions with inadequate understanding of overall portfolio needs and with insufficient knowledge as to the cost and feasibility of individual development projects. The military services have also identified needs and allocated resources separately, resulting in a fragmented fighting force.[4] Recognizing these issues, Deputy Secretary of Defense Gordon England issued a memorandum in September 2006, reinforced by another in February 2008, calling for the explicit use of capability portfolio management by all DoD components.[5] These directives were meant to reduce redundancy amongst development programs, improve joint interoperability, and increase efficiency in acquisition processes.[6] The Army currently has a number of capability portfolios under review, with reviews of precision fires and aviation complete, and nine other reviews currently in progress.[7]

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[3] DoD (2006)

[4] GAO (2007)

[5] These are, respectively: DOD (2006, p. 67); England (2008)

[6] DOD (2006)

[7] Six ongoing 'materiel focus' area reviews are: Tactical Wheeled Vehicles; Intelligence, Surveillance and Reconnaissance; Engineer Mobility and Counter Mobility; Combat Vehicle Modernization; Network Modernization; and Soldier Systems. Three ongoing non-material area reviews are: Training; Workforce Composition; and Information Technology. See: Defense Report (2010)

The first Capability Portfolio Review to issue recommendations focused on precision fire systems. On April 22, 2010, the review recommended the cancelation of the Non-Line-of-Sight Launch System (NLOS-LS) because the system and associated munitions were not cost-effective.[8] Speculated reasons for the decision include high per-missile cost of $466,000 as well as the lower need for the NLOS-LS and associated munitions when compared to other precision-fire munitions.[9] While cancelation may have saved resources going forward, an estimated $1.1 billion was dedicated to development of the NLOS-LS before cancelation.

Capability Portfolio Reviews are likely to be a mainstay of development oversight for the foreseeable future. However, relatively more specific portfolio reviews like the one addressing precision fires are a relatively new undertaking for the Army. Instead, focus has traditionally rested on broad capability requirement areas called Force Operating Capabilities (FOCs). The FOCs are relatively broad categorizations. For example, the lethality FOC is defined as the ability to destroy or neutralize adversaries, and includes within it many diverse types of systems to accomplish that goal.[10] However, FOCs actually contain systems serving very different specific capabilities at a basic level, which are defined as 'fundamental capabilities' here.

The three levels of system aggregation that are relevant to the process of portfolio management are shown in Figure 1.2. Represented at aggregation level two are the eleven FOCs defined by the Army. Meanwhile, RAND has performed a series of studies to examine the tradeoffs between the FOCs necessary to build the overall Army portfolio.[11] These cross-capability tradeoff decisions are represented at aggregation level one in Figure 1.2. But within FOCs such as lethality, very different systems need to be developed in order to provide more basic lethality capabilities to soldiers in the field. These fundamental capability portfolios of like weapons are represented at aggregation level three in Figure 1.2. As an example, consider the portfolio of small arms necessary to effectively engage different types of targets, such as individual enemy soldiers, armor, and structures, at various distances. Two different types of machine guns, which could act as substitutes in the equipping of soldiers, are considered to be part of the same fundamental capability portfolio, even if they have slightly different properties or uses. On the other hand a mortar, although it provides a lethality capability, would be considered to be part of a separate fundamental capability, since there is often no practical tradeoff between the use of small arms and mortars in the field. In total, prior to consideration of gaps within the overall lethality capability area, one must first assess whether

[8] Hicks (n.d.)

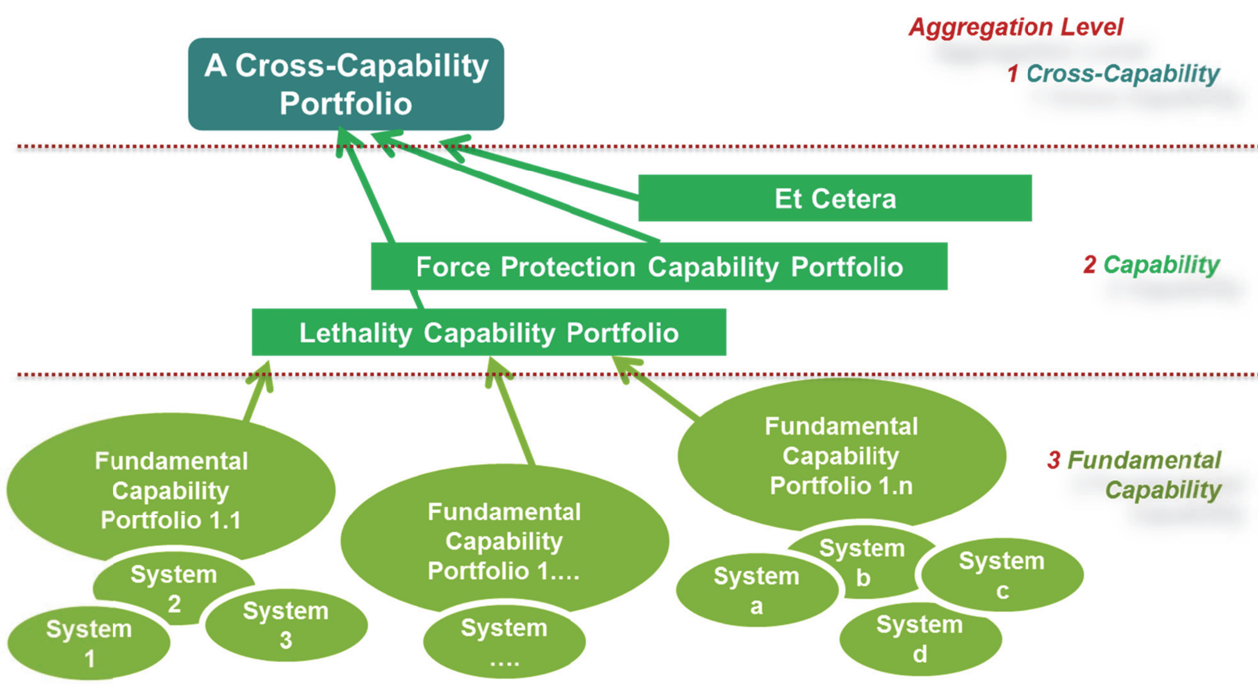
[9] Barkoviak (2010) discusses missile costs, while Gourley (2010) discusses the relative importance of the precision-fire munitions that were reviewed.

[10] The other Force Operating Capabilities are defined later in the dissertation. See Mackey (2008) for complete definitions.

[11] RAND research that addresses cross-capability portfolio allocation is discussed in detail in the literature review chapter.

investment in development efforts results in the right mix of systems to satisfy each of the specific fundamental capabilities. Moreover, portfolio management must make recommendations as to how many development programs to fund, which programs to terminate or suspend and when those decisions should be made, and must also develop alternative plans given inevitable delays and complications in development. This dissertation addresses all of these issues within the context of the fundamental capability portfolio.

Figure 1.2 - Capability Portfolio Aggregation Levels



The emphasis on fundamental capability portfolio reviews will result in more of a focus on 'smaller', less expensive weapon systems, which make up 80% of the Army's acquisition budget, and in some cases will make up the majority or even totality of systems within a specific, fundamental capability portfolio of like systems. Currently, research regarding cost growth, schedule delay, and cancelation within the development of weapon systems has tended to focused on 'Major Weapon Systems', which are defined by the DoD as requiring eventual research, development, test, and evaluation expenditures of more than $300 million, or eventual procurement expenditures of $1.8 billion.[12] Smaller systems, on the other hand, are under-studied, although development of such systems carries huge potential payoffs to troops on the ground. For example, the anti-improvised explosive devices (anti-IED) systems analyzed in this dissertation do not contain amongst them a single major weapon system.

[12] Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (2009)

One should not assume that results from previous research regarding major weapon systems would apply to smaller systems, especially in the context of the portfolio. It is likely that the rates of cost growth, schedule delay, and cancelation differ between major weapon systems and their smaller counterparts. Major Weapon Systems, due to their cost, are often the only development effort aimed at filling a particular capability gap. On the other hand, amongst smaller systems there are often close substitutes or even directly competing systems - developed independently by a rival company or mandated by the Army itself – that could fulfill a particular capability gap. As a result, in a portfolio management context, there is a question as to whether the development of closely related systems is wasteful redundancy on the one hand, or needed insurance on the other.

The development paths of major weapon systems will also diverge from those of smaller systems. Major weapon systems, such as combat vehicles, are often developed to include features meant to counter perceived future threats, which may give developers some scheduling leeway. Smaller programs, on the other hand, are often initiated to counter imminent, recently revealed threats, such as the use of novel IEDs by insurgents. For such systems, rapid development and fielding is of urgent importance given an environment in which casualties, rather than dollars, are often a determining factor in the decision to begin or sustain a combat mission or war.

In order to provide recommendations for efforts at the fundamental capability level, assessment of two fundamental capability portfolios, representing seventeen systems under development in fiscal year 2006, are presented in this dissertation. These consist of seven small arms and ten anti-IED systems. These portfolios were selected because of the large number of systems under development in each area and the importance of each portfolio to the Army's overall mission.

A fundamental capability portfolio review builds 'from the ground up' to assess how well individual developing Army systems together perform the multiple tasks expected of a fundamental capability portfolio. Only after performing portfolio analysis at this detailed level can one determine how well gaps in the overall capability area or across such areas are being.

The efforts undertaken in this dissertation shed light on how much individual systems cost to develop and how long development takes to complete. The development histories of individual systems, as well as the portfolio as a whole, are also compiled. This historical analysis is done to delineate the developmental obstacles and successes for a given fundamental capability. There is currently controversy regarding whether there are too many development projects being canceled, whether development projects can be better selected from the start so as to reduce cancelation, and whether the Army is too late to cancel problematic development projects. Through analytical examination of the developmental histories of two fundamental capability portfolios, this dissertation addresses the issue of whether the Army has made good decisions in a timely manner in regards to cancelation or doubling down for continued development of systems experiencing cost overrun and delay. The dissertation also draws some conclusions as to how development decisions for problematic programs, which experience cost overruns and/or delay, could be made in the future.

Chapter Two - Literature Review

The research described herein expands upon previous research in two significant ways. First, it considers all systems that contribute to a particular capability, both large and small, rather than focusing exclusively on major weapon systems. Second, previous portfolio analyses have focused on project selection within a broad capability requirement area or the optimal distribution of development funds across these capability areas. In contrast, since a capability requirement area contains dissimilar systems serving different specific functions, analysis carried out here focuses at the level of the fundamental capability portfolio.

Past Studies Focused on Major Systems

Prior research has generally focused on development related to major weapon systems, both because data are more readily available for these systems, and because development of individual major weapon systems represents a relatively large and high-profile portion of the total development budget of the military. Cost growth in major weapon systems, whereby development and procurement costs increase above prior estimates over time, has been a primary area of focus in past studies. Literature related to the phenomenon is particularly relevant because cost growth is associated with a variety of development problems that could lead to capability gaps in portfolios, including schedule delay, risk of cancelation, and reductions in actual versus expected system capability. Importantly, it should also be noted that the opportunity costs of funds lost to cost growth in one development project are alternate development programs that go underfunded or entirely unfunded as a result.

Surveying development in the 1960s, Perry (1969) found 40% cost growth amongst twenty one acquisition programs.[13] Cost growth in systems was also accompanied by schedule slippage of about 15% for studied systems.[14] Amongst causes of cost growth, 'technical uncertainty' was found to contribute 33% of total growth, while 50% was attributed to changes in program objectives after development had already begun. Interestingly, Perry (1971) found that European aircraft developers exhibited lower cost growth than their American counterparts, and attributed this at least partly to more stringent performance requirements at the end of initial development phases before committing to procurement. Based on this observation, Perry et al. recommended an incremental development strategy for US projects, delimited by milestones at which progress could be assessed.

[13] Perry et al (1969)
[14] Perry et al (1971)

In 1975, a few short years after finding evidence of the superiority of European aeronautical firms, Perry praised the newly available F-16 as superior to the French-built Mirage F-1 in both cost and performance. Reasons for this outcome were twofold: the extensive use of off-the-shelf subsystems in the aircraft, which simplified development, and extensive prototyping in development.[15]

Despite the implementation of reforms that mirrored those called for in the 1960s and 70s by Perry and others, including milestones built into the development process, cost-growth remained a stubborn problem throughout the next decades. Drezner et al. (1993), found that amongst 128 projects, cost growth averaged 20%, a number lower than reported in previous research because the systems studied by Drezner were still in development. In actuality, cost growth was found to be relatively stable since the mid-1960s. Moreover, no strong causal correlation was found that could ascribe cost growth to any single significant factor, because reasons varied widely between individual development efforts.[16]

More recently, Arena et al. (2006) utilized Selected Acquisition Reports (SARs) to quantify the magnitude of cost-growth in sixty-eight completed major weapon systems at 46%, mirroring the results from research forty years ago.[17] Again, few correlations were observed between overall system characteristics and cost growth. Bolten et al. (2008) analyzed thirty-five completed and on-going programs in order to determine causes of cost-growth in development and procurement. The study found evidence of 60% overall cost growth from initial estimates, resulting largely from decisions such as alterations to quantities procured, requirements increases, and schedule changes.[18]

Shifting from cost growth to rates of cancelation, the Final Report of the 2010 Army Acquisition Review was the broadest in scope yet of a group of studies providing policy recommendations to decrease rates of cancelation in major weapons systems. The review found that from 1990 to 2010, twenty-two major acquisition programs were canceled.[19] Even excluding high-profile cancelations in the Future Combat System (FCS) family of systems, termination represents sunk costs of 25% of available Development Test and Evaluation (DT&E) funding per year. Including FCS cancelations, 35% to 42% of Army DT&E funding has been lost to terminations.

While these studies suggest the scope of problems with major weapon systems, they are not the whole story. Smaller systems are important in their own right, and are often important components of major systems. More importantly, the Department of Defense spends only 20% of annual defense

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[15] Perry (1975)

[16] Drezner et al. (1990)

[17] Cost growth in these studies is usually calculated as final cost above the cost estimated at various milestones. In this case, cost was found to be 46% above milestone B estimates and 16% above milestone C estimates. Arena (2006)

[18] Bolten et al. (2008)

[19] Army Acquisition Review (2011)

acquisition funds on major weapon systems.[20] Results from studies on major weapon systems do not necessarily apply to the successes and failures of development of smaller systems. Moreover, while the 2010 Army Acquisition Review is a milestone in highlighting the amount and magnitude of cancelations within the budget, this dissertation aims to expand upon that work by providing a full picture of how terminations have affected the types of capabilities the Army possesses and the types of gaps in capabilities soldiers experience in the field by examining smaller programs that constitute 80% of annual DoD acquisition funds.

Portfolio Analyses Have Not Focused at the Fundamental Level

While portfolio analyses have gained prominence as a result of DoD mandates, research related to these analyses have been focused on the cost-effective trade-offs between wide-ranging Force Operating Capability (FOC) areas or tradeoff decisions within one such FOC or capability portfolio, and until recently have not emphasized how individual systems work together to perform each fundamental capability .[21]

Table 2.1 provides a listing of the eleven FOCs that the Army traditionally uses to categorize systems. The first two columns of the table list the FOC number and name, while the last two columns give some examples of the specific capabilities provided by each FOC. For example, FOC number seven, Force Protection, subsumes systems that contribute to personnel and asset protection. The areas included within this FOC are on-asset and off-asset protection, and similarly on-body and off-body personnel protection.[22] Anti-IED systems, one of the fundamental capability portfolios studied here, is much more specific than any of these categories used previously, and in fact can cut across these categorizations since, for example, IED jamming devices can protect both assets and personnel both on- and off-vehicle and personnel.

[20] Defense Update (2009)
[21] Force Operating Capabilities are operational capabilities which, when achieved in aggregate, would fulfill the vision of the future Modular Force. See: Mackey (2008)
[22] Chow et al. (2009)

Table 2.1 – Component Capability Examples of Force Operating Capabilities

#	FOC	Example 1	Example 2
1	Battle Command	Command and control	Decision superiority
2	Battlespace Awareness	Intelligence information	Manage knowledge
3	Mounted/Dismounted Maneuver	Mobility	Urban operations
4	Air Maneuver	Aviation support	Reconnaissance
5	Lethality	Precision	Automated fire
6	Maneuver Support	Understand battle space	Freedom of maneuver
7	Force Protection	Personnel protection	Asset protection
8	Responsiveness / Deployability	Airlift / sealift	Theater access
9	Maneuver Sustainment	Power and energy	Force health
10	Training, Leadership, Education	Leadership training	Unit performance
11	Human Engineering	Reduce soldier load	Decrease task complexity

Source: Mackay (2008)

One prominent example of cross-FOC portfolio analysis is the research set forth in three RAND monographs - the *Toward Affordable Systems* series (referred to below as *TAS I, TAS II, and TAS III* respectively).[23] These publications developed a methodology to select between competing projects given the capability provided by each system and the cost of development and procurement associated with each system. The model developed also explicitly incorporates uncertainties in development outcomes, such as the possibility of project failures, cost overruns, and budget cuts. The model suggests the need for development safety margins to ensure that, even when uncertainties result in unfavorable outcomes for some systems, there are other systems being developed and made available to meet capability requirements.[24] The *TAS* studies also represent an initial attempt to expand analysis beyond major systems and consider both major and smaller systems under development.

In contrast to the *Toward Affordable Systems* publications that focused on the broad level of inter-FOC tradeoffs, this dissertation focuses at the fundamental capability level on systems that are likely to be compliments or substitutes for one another in the task they perform. Before a portfolio analysis is conducted at the capability-area level (e.g., within the lethality category) or cross-capability level (e.g., tradeoffs between lethality and force protection systems), it is important to perform analysis that allows policymakers to reduce wasteful redundancy in system development on the one hand, while at the same time retaining enough development programs to provide a safety margin so that if

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[23] Refer to the references section for full citations.

[24] In the context of this dissertation, the term 'safety margin' is meant to convey the need to hedge against development cancellation, shortfalls in performance, or inflated final procurement costs by supporting multiple parallel development efforts within a fundamental capability portfolio.

some programs fail, gaps within the fundamental capability portfolio can still be filled. Otherwise, portfolio analyses will not be cost-effective in meeting Army capability requirements. Once the Army has well-balanced and efficient individual fundamental capabilities, aggregation can occur in performing a portfolio balancing act on individual capability areas (made up of individual fundamental capability portfolios), which in turn allows an assessment across all capability areas, Army-wide.

Another goal of this dissertation is the consideration of how development decisions are made dynamically, rather than at a static decision point, and analysis of how delays in development lead to capability gaps in the portfolio. The evaluation carried out in *TAS I* was expanded in both *TAS II* and *TAS III* and refined to include the possibility of unsuccessful outcomes in the development process, the possibility of cost overrun, and the uncertainty in the budget available for acquiring, operating and maintaining systems. As stated previously, this important component of the model introduced the conceptual need for substitutable projects within the portfolio so as to provide a safety margin when development efforts fail to produce a fielded system. While this concept is important, three important facets are added here.

First, these previous studies focused on the selection of systems for initial or continued development at a single decision point in 2006. As a result, nothing was known about what eventually became of these systems in subsequent years, including whether they were eventually fielded or not. In contrast, the research effort contained herein tracks each system's development over the period from FY 1998 to FY 2013 (the current budget year) and forward to FY2015 (planned expenditures as projected by the Army). Consideration of the full set of in-development systems thus reveals a much more comprehensive picture of whether developing systems will under-provide (or over-provide) capability requirements.

Second, previous results only provide a static snapshot of Army capabilities. It may be that systems for a particular Force Operating Capability are more prone to failure in completing the RDT&E phases than those for other FOCs. If that were the case, development policies would have to be flexible, depending on the particular area of focus. This dissertation addresses this question by providing analysis of how development occurs for a cohort of all systems, defined here as those systems in various stages of development and recorded in Army budgetary documents as of FY 2006, in two separate fundamental capability portfolios over the span of development efforts for the systems from 1998 to 2015.

Third, previous analyses considered whether existing programs should be kept or cut, but did not address whether the Army should allow fewer systems to reach the technically mature 'ready-to-be-fielded' (RTBF) stage in order to save money to perform RDT&E on other systems.[25] Within a tight budget, it might be better to halt systems at an earlier stage based on shifting needs or warning signs within individual development efforts. This dissertation addresses some of these RTBF systems in order to assess whether large portions of the budget are being used inefficiently to fully develop systems that are not fielded in the end.

[25] RTBF systems are systems that have completed the stage of engineering and manufacturing development. They may even have passed Milestone C. However, while their prototypes may have been made, these systems are not in limited or full rate projection.

Chapter Three - Data and Methods

A portfolio case study methodology is utilized to first fully describe the characteristics and purpose of each in-development system under review and then determine how those systems complement each other in fulfilling Army requirements within a given fundamental capability portfolio.

Data collected in this study answer a series of questions for a group of developing systems: what does the system do, how much did it cost to develop the system, how long did it take to develop, was the system fielded, and how does the capability provided by the system relate to that provided by other systems, both under development and previously fielded?

System and Portfolio Segment Selection

Data collection focuses on providing detailed descriptions of a cohort of Army systems in development in FY 2006. The primary source of system identification, development costs and schedule data were Army Research, Development, Test &Evaluation Budget Item Justification sheets, referred to as 'R2s', which were obtained from the Defense Technology Information Center (DTIC) website.[26]. These official reports from the Army provide itemized budgetary information for system development, and are available online beginning with fiscal year 2000 and currently available through fiscal year 2013. Each R2 generally provides two years of historical data, as well as two or more years of expected future expenditures.[27] As a result, past budgeted and future expected RDT&E expenditure for most systems could be tracked from fiscal year 1998 to 2012 (actual) and 2015 (as projected by Army), resulting in up to seventeen years of available data. The systems under development in 2006 were at the midpoint between these two dates, allowing both an examination of historical development efforts and an understanding of development outcomes.

It should be noted that the R2s do not include information on all of the systems under development by the military. Most notably, systems that are urgently needed often go through a rapid acquisition process that bypasses the traditional research stages documented in R2s. The dissertation overcomes this limitation in two ways. First, although development cost and schedule data cannot be obtained for all systems, important relevant systems (for which information is publicly availableR2) are still accounted for in relation to the systems of focus when constructing the portfolio case studies.

[26]Available at http://comptroller.defense.gov/ and http://www.dtic.mil/dtic/. R2s are exhibits in the justification books that enumerate department of defense planned fiscal year budget as presented in the President's annual budget submissions.

[27] The number of years of expected future budgetary information varies by system.

Second, the emphasis of the dissertation is on how the traditional research and development process can be improved, with reference to the rapid research and acquisition strategies only where applicable.

Following the identification of all systems listed in FY 2006 R2s, systems were categorized based on the FOC that they provide. Initial selection screening then focused on two important FOCs, Force Protection and Lethality.

The Lethality and Force Protection FOCs were selected because of their relative importance to the military. Lethality, which focuses on systems such as small arms and missiles, is obviously of great importance on the battlefield. However, there is some question as to what focus developing systems should have in an anti-insurgency environment. Similarly, the Force Protection FOC, which includes anti-IED functions, has been a major focus of new development over the past decade due to the contingencies in Iraq and Afghanistan.

A total of 104 unique systems were identified from the FY 2006 R2s that belong in the Lethality and Force Protection FOCs.[28] Each of the systems was then categorized more specifically, based on the particular function they were developed to perform. The functional categories with five or more systems are listed in **Table 3.1**, while a categorized list of all 104 systems is provided in Appendix A.

Table 3.1 - Lethality and Force Protection Groups with Five or More Systems

Function	Number of Systems
Air Defense	7
Anti-IED	10
Artillery	5
Ground Vehicles	5
Missiles	12
Small Arms	7
Targeting / Queuing	6
Uniforms & Clothing	6
Vision & Weapon Sights	5

Source: Calculated from R2 Budget Item Justification Sheets

[28] Note that some systems arise from technologies matured under other, concurrently developed systems. In these cases, each system is counted as a unique case.

Two portfolio segments, highlighted in **Table 3.1**, were selected for in-depth analysis based on the following criteria:

1. Are there enough systems under development in the portfolio segment to allow for a meaningful discussion? In many cases, only one or two systems were under development in FY 2006, which would have proved inadequate for analytic purposes.
2. Is the portfolio likely to include a mix of both large and small systems? Systems that are costly to develop and procure are already the subject of numerous studies. Given the focus on smaller systems it was important to avoid categories, such as vehicles, that might be made up almost exclusively of major systems. Instead, categories that featured a mix of expenses in development and scope of procurement were preferred.
3. Is the portfolio segment of high importance? To increase relevancy of the dissertation, it was decided to focus on systems that are the most essential in the field.

In the end, the anti-IED and small arms categories were deemed to best satisfy the above criteria, resulting in a focus on a total of 17 weapon systems.

Given the current geo-political environment, anti-IED systems are clearly an area of importance. Moreover, an adequate anti-IED strategy requires a variety of systems performing different functions that must all work together, from mine detection to mine neutralization. Furthermore, these systems provide an interesting area of study, since systems are developed in a variety of ways, from 'ground up' via the traditional Army RDT&E process, to extensive use of Commercial-Off-the-Shelf (COTS) and Government-Off-the-Shelf (GOTS) technologies.

Small arms systems operated by individual soldiers or teams (crew-served guns), are also a high priority. In rugged environments that do not allow for access by larger systems, small arms are often the primary provider of immediate lethality capabilities in the field. Moreover, the area deserves analysis given the lack of innovations in small arms over the last decades.

Data Collection Methodology

For each individual in-development system, data collection proceeded in two phases. In the first phase, data was obtained from a wide variety of sources to build an understanding of the capability the system is currently meant to provide, as well as a historical record of how capability expectations have changed over time. In the second phase, data related to the development process, including schedule of passage through the various developmental stages – defined and discussed in more detail below - and yearly development cost were collected.

Capabilities of developing systems

System capability can be defined as the functional need that a system addresses and the extent to which it can fulfill that need. Capability also determines how the system in question relates to other systems in the development portfolio. System capability and current development status information were extracted from a variety of sources, each of which has some unique features dependent on the particular system under review. The Defense Technology Information Center has a large collection of military documents and briefings related to systems, while R2s contain system development descriptions that are updated each year. Jane's Online and the Army Science & Technology Master Plan, updated annually, are other sources of in-depth description, while Inside Defense provides unique updates on system development efforts. In a few cases, interviews carried out in the past by various authors with key members of system development oversight were used.

For each system, sources were sought that provided information about how capability expectations changed over time as development progressed. In many cases, revisions were made to individual system requirements that resulted in increased requirements for a system beyond what it was originally intended, or requirements were modified so that the system served a slightly different purpose based on new operational requirements. In other cases, development problems also meant that the scope of system capability expectations was reduced – in a few cases dramatically. In every case, it proved possible to document major changes to capability requirements over time.

The same sources listed above were utilized to identify and describe 'legacy systems' – defined as older systems that the new crop of systems is expected to improve or replace - as well as any new development efforts that are on the horizon that could supplant systems in the study cohort in the future. As a result, it is possible to gauge the marginal improvement that the development system provides over older systems that provide a similar capability, or the same capability at a more limited scale.

Schedule and Cost

Development Stages and Budgetary Data

Development of new technologies generally progresses through a series of stages. These are summarized in **Table 3.2**, which provides the names of the development stages, a brief definition of each, and indicates, in the third column, whether budgetary data from that stage is directly relevant to this dissertation.

Table 3.2 - Development Stage Descriptions

Development Stage		Definition	Applicability
6.1	Basic Research	Study without products in mind	No – Not system specific
6.2	Applied Research	Application of knowledge to develop useful devices	Rarely – If system specific
6.3	Advanced Technology Development	Develop prototypes	Yes
6.4	Advanced Component Development and Prototypes	Prototypes in operating environment	Yes
6.5	Engineering and Manufacturing Development	At or near planned operational system	Yes
6.6	Management Support	Testing facilities and equipment	No – Cannot be assigned
6.7	Operational Systems Development	Upgrades to fielded systems	Yes – Product improvement

Source: DOD Bulletin 7000.14-R[29]

'Basic Research' is conducted at stage 6.1, and development funds listed under this category are likely to be described as applicable to a type of technology, rather than to individual systems. While these nascent technologies are very likely to end up in more mature systems, there is no practical way to attribute the funding that applies to these technologies to individual systems that may, in fact, employ those technologies at a later time.

Applied Research is conducted at stage 6.2. Again, expenditures under this stage are usually applied to early technology rather than systems, making data unsuitable for collection. In a few cases research related to specific, named systems was conducted at stage 6.2 When this was the case, the data was collected for analysis.

At stage 6.3, titled Advanced Technology Development, specific systems are expected to arise from nascent technology applications, and the majority of 6.3 funds are tied to specific, identifiable

[29] DOD (2012)

systems. This is also the case for 6.4 and 6.5 funding, which represents more advanced stages of system development. Development of individual systems will generally be tracked from stage 6.3 through the Advanced Component Development and Prototypes (6.4) and to the Engineering and Manufacturing Development (EMD) (6.5) stages.

Stage 6.6 represents aggregate funds designated for testing facilities and equipment. This funding is utilized by a variety of development efforts and cannot be practically linked to any individual system. Moreover, systems are never 'in' the 6.6 stage, and funds used for management support are therefore not relevant to a system's development timeline.

Finally, stage 6.7 applies to improvements for already fielded systems. This stage of funding is used, for example, if a fielded system is modified to improve performance or provide a new function. This funding was relevant to some of the systems under study, and was collected when available.

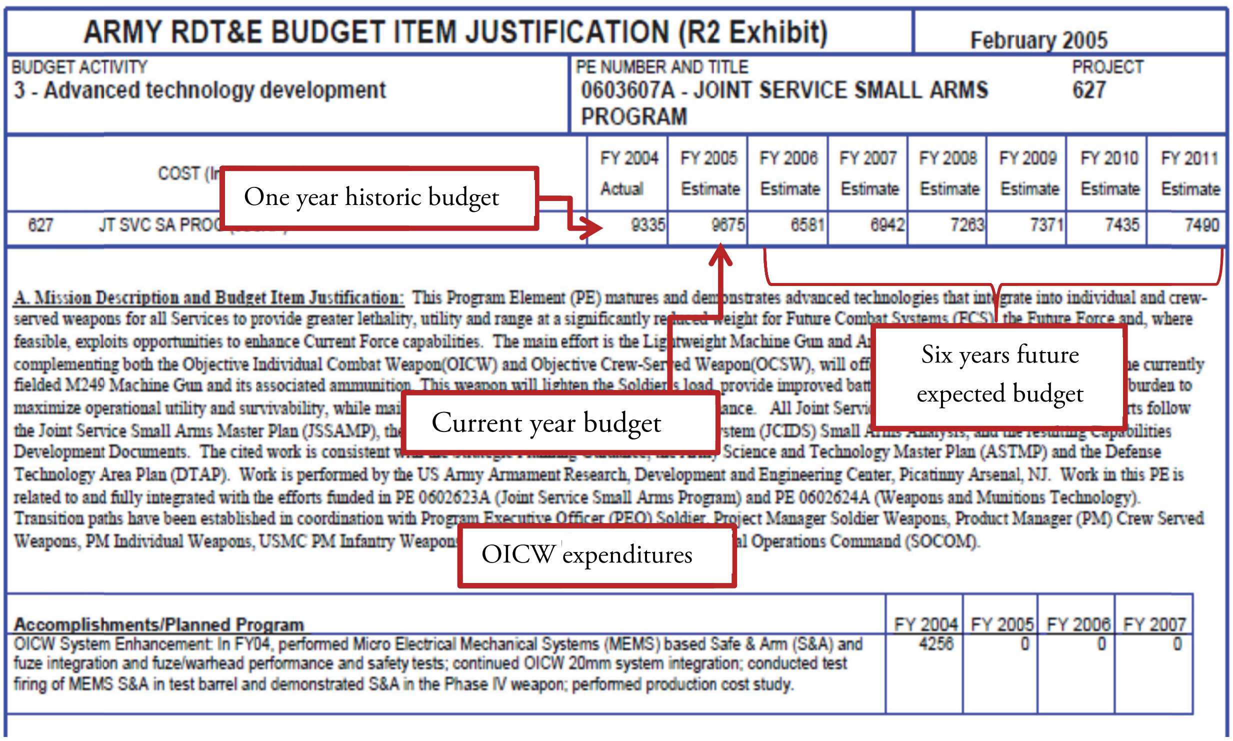
Yearly schedule information that tracks system progress through the different development stages can be obtained from the R2s. In some cases, systems proceed in a simple fashion from 6.3, through 6.4, and are fielded following 6.5. In other cases, complex systems may be under development in stage 6.4, but components have been sent back to stage 6.3 for further development. The R2s provide a clear indication of both of these cases.

It should be noted that the R2s are not the sole source of schedule information included here. Because uncertain events are of interest, yearly data is not always adequately specific. Data collection included other varied sources such as official Army documentation and media reports in order to pinpoint when certain events occurred (for example, the use of sophisticated IEDs against US troops in Iraq) that caused the need for urgent development of systems and to pinpoint exactly when system development began to deal with those threats. Finally, in cases of system cancelation, the timing of cancelation and reasons for termination were collected; this information is often available from R2s, but other more detailed sources were used to confirm or find precise dates and reasons for cancelation. This data collection effort should result in a reliable and accurate timeline for each study system.

Development Cost

Development costs, specifically RDT&E costs, are organized under identifying codes called 'program elements' (PEs) in the R2s. Program element codes generally group similar projects together. As an example, for FY 2006, PE 0603607A is titled 'Joint Service Small Arms Program.'[30] The relevant R2 is reproduced in **Figure 3.1**.

Figure 3.1 - R2 Exhibit for Program Element 0603607A



Source: Defense Technical Information Center

In each R2, a budget totaling all of the development efforts undertaken in a PE is listed first. As indicated in **Figure 3.1**, one year of historic data is usually provided, along with expected expenditures for the current year and, depending on the particular formatting of the R2 exhibit, as many as six years of planned future expenditure. Under each program element, the overall budget amounts are apportioned specifically to individual project numbers. So, in **Figure 3.1**, of the total budget of $9.335 million allocated in FY 2004 (shown near the top of the table), $4.256 was set aside for development of the OICW, with no current or future expenditures planned for the weapon under this PE number (shown at the bottom of the table). Not as much budget data is provided under individual projects as top-line program elements. For individual systems, it is usually the case

[30] The specific R2 can be viewed, as of October 2012, at: http://www.dtic.mil/descriptivesum/Y2004/SOC/1160402BB.pdf

that only one year of historical data, the most recent budgeted spending for the current fiscal year, and planned spending for two future fiscal years are presented. This simply means that less future projected spending data is available for individual projects than for program elements, but it does not impede collection efforts. This is because project spending further down the road will be obtained from R2s from subsequent fiscal years - 2007 through 2013 in the case at hand.[31]

One caveat to the above methodology is that it is sometimes not possible to extract budget data for individual projects from the R2s. Itemized lines describing specific development efforts are included in each R2, and it is sometimes the case that several systems are grouped together in descriptions. For example, consider the following description from the FY 2004 R2 under PE 1160402BB (underlining added):

> FY02 Continued the development of the <u>Anti-Materiel Payload Rifle</u>. <u>Completed Advanced Sniper Weapon Fire Control System</u> and <u>Active Denial Technology</u>. Initiated <u>Remote Standoff Capable/Remote Operated Small Arms Mount</u> to increase effectiveness and operator survivability.[32]

The Anti-Material Payload Rifle is clearly an individual system, and in fact refers to the XM109 Anti-Material Payload Rifle, which is analyzed in one of the portfolio reviews included below. However, it is unclear whether the Advanced Sniper Weapon Fire Control System is unique to that system, or common to a particular class of sniper rifles. The Active Denial Technology described in the passage appears to be an area of technological study rather than a unique system undergoing development. Finally, the Small Arms Mount described in the passage appears to be a system that is complimentary to the Payload Rifle, but unique in its own right. As a result, it is difficult to ascribe the dollar value associated with this research effort to any one system. In the data collection process, aggregate line-items of this kind were collected, but in the discussion that follows only cost data that could be clearly attributed to the particular system in question are presented. While this results in an inaccurate cost for the system and tends to underestimate overall development costs, precise dollar values are not essential in what follows. The systems generally fall into two groups: relatively high-cost, high-ambition systems that are expected to provide a large share of future capabilities in the portfolio, and low-cost systems that often provide marginal improvements over legacy systems. The importance and approximate cost of systems are more important to the conclusions reached, and precise cost estimates would not materially alter those conclusions.

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[31] Prior year R2s are not available for FY 2000 documents, as these are the earliest documents available online.

[32] This R2 document is available at: http://www.dtic.mil/descriptivesum/Y2004/SOC/1160402BB.pdf

Chapter Four - Summary of Systems

On the following page, **Table 4.1** shows the current status and outcomes for all seventeen small arms and anti-IED systems that were under development during FY2006. The table is ordered by total amount of RDT&E funding spent on each system.[33] The Airborne Standoff Minefield Detection System required the most development funds over time, while the .338 Norma Magnum Lightweight Medium Machine Gun (LWMMG) required the least.[34] Subsequent chapters of this dissertation will discuss the functions of each system in more detail.

In **Table 4.1**, entries are shaded to indicate the outcome of the development project. Entries shaded red are currently designated by the military as canceled. Cancelation does not indicate that the technology under development has been completely lost. For example, the XM25 munition launcher, a system currently under development, utilizes technology first developed under the canceled OICW. Canceled systems can also be restarted at a later date. Yellow entries in **Table 4.1** are currently still in development, with recent funding spent on some stage of RDT&E and a decision for full procurement not yet made. Blue entries have not been officially canceled, but show no current RDT&E spending and are not being procured. These systems are categorized as 'Not Yet Procured' here. Development efforts in this category can be in one of two possible states. First, development failed to produce a usable system in terms of performance and/or cost, and the development process was halted but never officially labeled as canceled. Second, development resulted in a usable system that was not procured, due to the decision to field an alternative system, or due to changing requirements.[35] Systems in the second state are referred to herein as 'Ready-to-be-Fielded', or RTBF. In fact, all three of the 'not yet procured' systems analyzed here are probably RTBF systems. The Scanjack system is the product of the Swedish military, and has already shown value in the field. The EDIT system has shown a high level of usefulness, although further development may be needed for use in a counter-insurgency - rather than peacetime demining –

[33] Funding data here and in all subsequent sections of the dissertation are in then-year, as opposed to current-year, dollars.

[34] These are funds that apply directly to the system in question. As discussed in the Data and Methods section previously, a large amount of funding is also spent in aggregate on multiple development systems at once – the most common examples of this are Advanced Concept Technology Demonstrations (ACTDs), in which multiple systems are demonstrated. In general, the more individual costs associated with a system, the more aggregate costs are likely to be as well, so that the ordering of the programs in **Table 4.1** is generally the same as that seen under full accounting, if aggregate funds could somehow be partitioned between systems.

[35] For each of the systems in this category, in-depth analysis is undertaken in the chapters that follow to ascertain why the individual system was not procured.

environment. Finally, the extent to which the XM109 sniper rifle is ready for duty in actual combat is not known, but development is likely to be at a highly advanced level since the system was competed against similar sniper rifles to select a model for procurement.[36] Finally, green entries represent development projects that resulted in a unique system, which is being procured at a rate commensurate with 'low-rate initial production' (LRIP) or more, with the concrete expectation of full-rate production in the near future.[37]

Table 4.1 - Cost, Time in Development, and Current Status of All Focus Systems

System Name	Designation / Accronym	RDT&E Total $ Millions	Total Fiscal Years RDT&E	Status
Airborne Standoff Mine Detection System	ASTAMIDS	254.873	21	In Development
Ground Standoff Mine Detection System	GSTAMIDS	172.015	19	Cancelled
Objective Individual Combat Weapon	OICW / XM29	163.705	14	Cancelled
Advanced Crew-Served Weapon	ACSW / XM307	161.941	14	Cancelled
Counter Defilade Target Engagement System	XM25	119.1	6	In Development
Autonomous Mine Detection System	AMDS	112.071	13	In Development
Husky Mounted Detection System	HMDS	87.231	4	Procured
Mongoose Explosive Standoff Mine Clearer	Mongoose	80.079	5	Cancelled
Lightweight Small Arms Systems Light Machine Gun	LSAS	74.382	11	In Development
Shortstop Electronic Protection System	SEPS	23.575	8	Procured
Change Detection Workstation	CDWS	15.774	3	Procured
Anti-Materiel Payload Rifle	AMPR / XM109	9.049	9	Not Yet Procured
Electromagnetic Wave Detection and Imaging Transceiver	EDIT	6.443	5	Not Yet Procured
M240L	M240L	4.899	7	Procured
ScanEagle UAV	ScanEagle	3.165	1	Leased from private company
Scanjack Mine Sweeper	Scanjack	0.959	1	Not Yet Procured
338 Norma Magnum Lightweight Medium Machine Gun	LWMMG	0.25	1	Procured

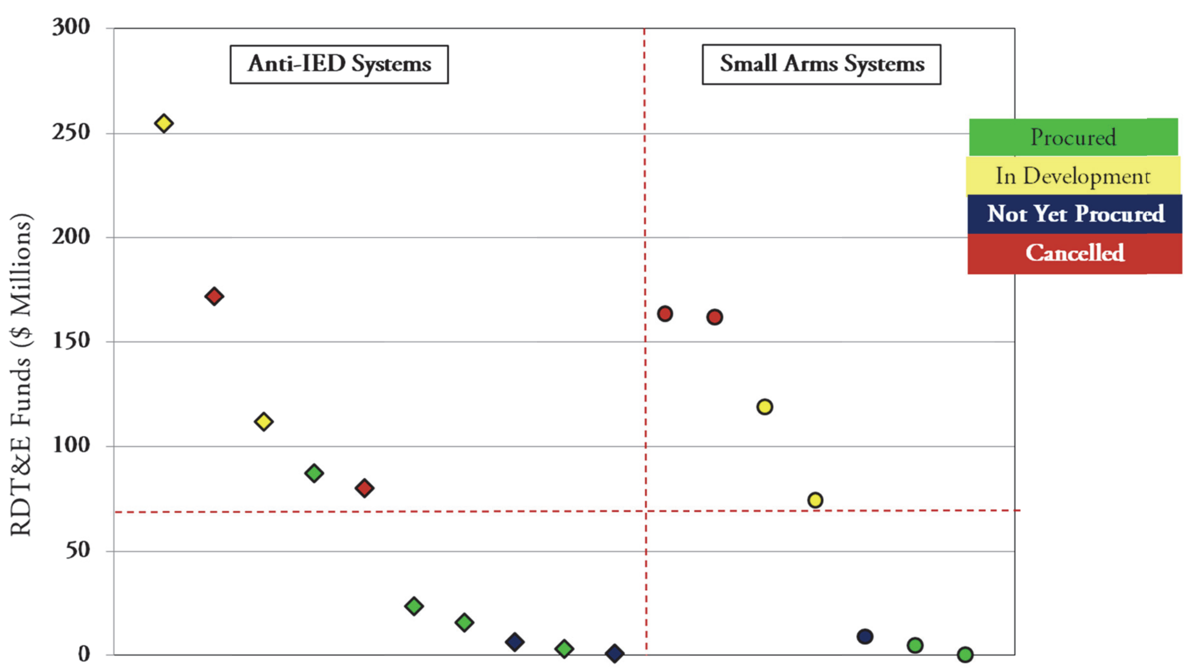
[36] See the relevant portfolio reviews for further discussion surrounding each of these systems.

[37] Note that full rate production can vary widely in quantity and cost. Procurement of individual small arms systems, such as a carbine, may require many thousands of units to be procured in order to fulfill capability requirements. On the other hand, UAVs of a specific class and purpose may require system procurement numbering in the teens or less.

From **Table 4.1**, it is apparent that the Army is more successful at fielding systems when they result from lower-cost RDT&E programs. In fact, the systems generally separate into two distinct types. The nine systems that cost the most in terms of RDT&E dollars spent from, the Airborne Standoff Mine Detection System to the Light Machine Gun (LSAS), tend to be more ambitious projects, in that they develop something new - a novel gun, a new unmanned platform, or an innovative and complex electronics system. ASTAMIDS and the Ground Standoff Mine Detection System, twin programs meant to provide standoff mine detection capabilities from the air and ground, respectively, represent such ambitious systems. In general, these systems are also intended to provide larger capability gains than comparatively cheaper-to-develop systems, although that is certainly not always the case.[38] The eight systems at the bottom of the table tend to represent military testing of systems developed outside of Army RDT&E, upgrades to systems developed by commercial companies, upgrades to existing Army systems, or development of less expensive, less complex systems.

The observations discussed above are illustrated visually in **Figure 4.1**. The figure is split between anti-IED systems at the left, and small arms systems at the right. Systems are ordered from most RDT&E expense to least in both cases.

Figure 4.1 - Anti-IED and Small Arms Systems Costs and Outcomes



[38] Individual cases will be discussed in the portfolio reviews that follow.

Nine high-cost systems are above the horizontal red dotted line in **Figure 4.1**, and all cost over $70 million, each. This relatively high-expense group contains only one system that was procured (which is the third least-expensive system within the group). The relatively high-expense group also contains four cancelations and four systems still under development. On the other hand, a group of eight relatively inexpensive systems lies below the red dotted line in the figure, and none cost over $25 million to develop. Five of these systems have been procured and three appear to be ready-to-be-fielded.

When the systems are separated into these two groups of relative expense, it becomes clear that the Army has had difficulty in successfully transitioning its more expensive programs from research and development to procurement. Since more expensive programs drain more from an already stressed budget, this pattern represents a serious problem for the Army.

Table 4.2 summarizes development outcomes based on RDT&E dollars spent. While four programs were canceled compared to six 'procured' (with the caveat that the ScanEagle is being leased rather than officially procured), the canceled programs represent 45% of RDT&E funding dollars, compared to only 10% for procured programs. Another 43% of funds were spent on systems still in development. Only 1% was being spent on Not-Yet-Procured systems. As discussed in chapter two, recall that the final report of the 2010 Army Acquisition Review found that historically, 35% to 42% of Army RDT&E funding on major weapon systems has been lost to termination, which is very similar to the 45% of funds lost to cancellation amongst the sample of 17 small systems studied here. Thus systems, whether or not they are designated as major systems, seem to face the same serious problem of losing a third to a half of development funds to cancelation.

Table 4.2 - Outcomes by Percent of Total RDT&E Dollars, All Systems

	Number of Development Programs	Percent of Total RDT&E Dollars
Cancelled	4	44.80%
In Development	4	43.46%
Not Yet Procured	3	1.28%
Procured	6	10.44%
	17	100%

As **Table 4.3** shows, four of the nine relatively more expensive development programs have been canceled. Four are still in development. Only one of the nine more expensive systems was eventually fielded, representing an 11% success rate in terms of bringing a system to the field. This compares unfavorably to the eight less expensive systems, where five fielded systems represent a 56% success rate.

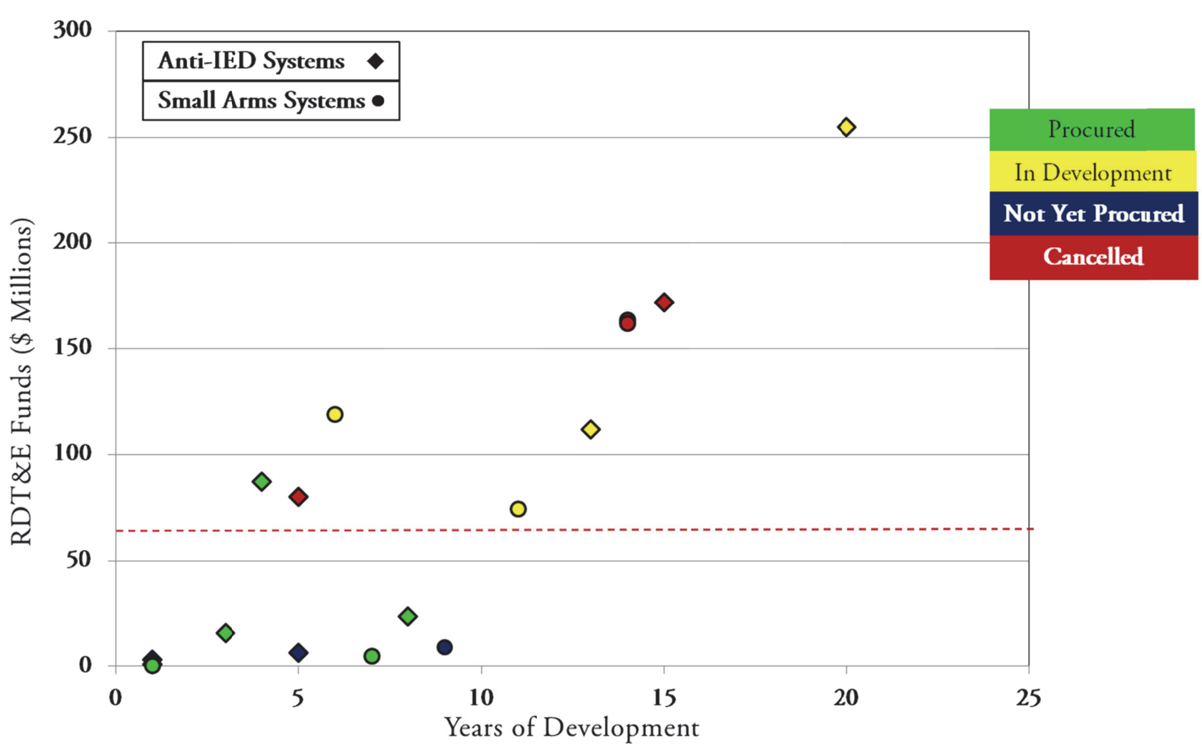
Table 4.3 - Outcomes by RDT&E Expense Level, All Systems

	Total	Top Nine	Bottom Eight
Cancelled	4	4	0
In Development	4	4	0
Not Yet Procured	3	0	3
Procured	6	1	5
	17	9	8

Four of the nine more expensive RDT&E programs are still in development. While in the future they may still result in successful systems, these development efforts have already averaged over twelve and a half years, which is much longer than original planned and with development still ongoing in each case.

Figure 4.2 Plots RDT&E funds spent against years in development for each of the systems. It is clear from the figure that high expense is highly correlated with the amount of time spent in development.

Figure 4.2 - RDT&E Expenditure versus Years in Development, All Systems



The XM25 program, which develops a soldier-borne smart-munition weapon, has been under development for six years as a standalone system. However, as noted above, the concept has actually been under development since 1994, when the XM25 was a part of the Objective Individual Combat Weapon (OICW) program. If that is taken as the true starting point of the XM25, the long development of this program alone would raise the average length of the four programs still in development from twelve and a half years to just over 16 years. This should cause concerns about the timeliness of development, as each of the development efforts has stretched across major portions of the conflicts in Iraq and Afghanistan without producing usable systems. This length of time in development also compares unfavorably with fielded systems shown previously in **Table 4.1**, which have spent four years, on average, in RDT&E.

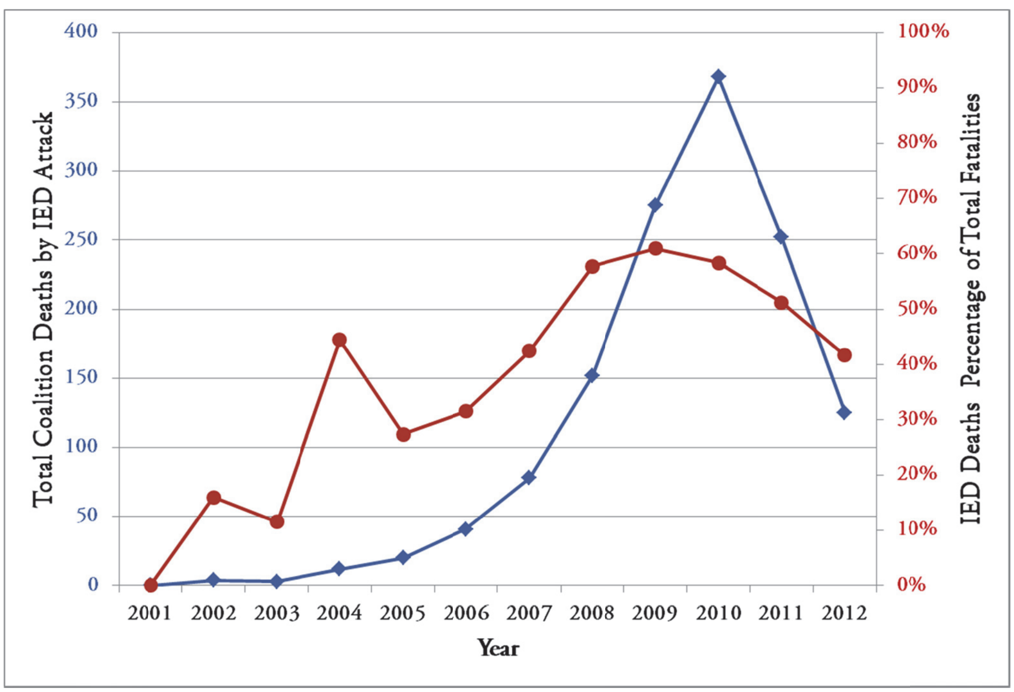
The following two chapters consider the effect that delays and cancelations in development have had on the small arms and anti-IED portfolios, respectively.

Chapter Five - Anti-IED Systems Portfolio

The role of portfolio analysis in driving development decisions can be illustrated through an examination of the anti-IED fundamental capability portfolio. The portfolio is characterized by a mix of relatively expensive, ambitious systems that have been under development for an extensive period of time within the traditional RDT&E process, and 'smaller' systems that were developed under the pressure of urgent need, usually outside of traditional channels. As IED attacks escalated in Iraq and then Afghanistan over the last decade, time to field was vital for these systems.

For much of Operation Enduring Freedom, IED fatalities amongst coalition forces have represented an escalating percentage of total hostile deaths in Afghanistan. From 2008 to 2011, IED incidents caused the majority of deaths amongst coalition forces, peaking in 2009 when just over 60% of fatalities were IED-related (**Figure 5.1**).

Figure 5.1 - Fatalities Caused by IED Attack, Operation Enduring Freedom



Source: icasualties.org[39]

[39] icasualties.org 'Operation Enduring Freedom' (n.d.)

While decisions related to the development and procurement of anti-IED systems can be justifiably based on the importance of lives saved, the development of these systems is also important within the context of economic benefit and cost considerations. As of December 2010, 1.25 million service members had returned from Iraq and Afghanistan. Of that number, 650,000 were treated in Department of Veteran Affairs medical facilities for a wide range of medical conditions. Available numbers suggest that from 2001 to mid-2011, the United States had already spent $31.3 billion on medical care and disability benefits for veterans. Recent estimates suggest that over the next forty years, present value medical costs and benefit claims for veterans returning from Iraq and Afghanistan would range between $600 billion and $ 1 trillion.[40]

These costs dwarf research and development costs for all the anti-IED systems examined in this portfolio, and suggest the potentially large opportunity costs associated with delaying the fielding of important anti-IED systems.[41] The systems examined in the anti-IED portfolio have the potential to produce large payoffs to the Army, despite the fact that none of the systems would be considered Major Weapon Systems by the standard definition.

Through analysis of this portfolio, it becomes clear that although development efforts for anti-IED systems has at times been problematic, with development efforts criticized for inefficient duplication and lack of transparency, major accomplishments have been achieved by the armed services over the last ten years through a rapid-equipping, trial and error approach, and through an increase in the supplemental use of COTs and GOTs components and systems. However, one cannot expect capabilities to arise from commercial technologies alone. Some capabilities can only be achieved by efforts that flow through traditional channels of RDT&E because much of anti-IED system development is complex, unique, and almost exclusively of military interest. As a result, there is a continued need for the overhaul of the traditional RDT&E system. Lessons can be learned from development efforts that have lasted for over twenty years in one such case, resulting in the lack of a vital IED detection capability over much of the past two key contingencies.

For over a decade, the United States military has battled against insurgents in urban and complex rural environments in both Afghanistan and Iraq. Facing an escalating usage of IEDs, the Army has scrambled to provide detection and neutralization systems in theatre that keep up with quickly evolving threats.

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[40] Bilmes (2011)

[41] An economic benefit/cost analysis for anti-IED development would have to include many other factors such as the acquisition and operating and maintenance costs of the systems. An analysis considering the benefit and cost of accelerated development and earlier deployment of anti-IED systems would be yet more complicated. However, in this particular case where human lives are involved, the traditional benefit/cost analysis is unlikely to be appropriate. A comparative analysis of how many lives would be saved by allocating resources to anti-IED systems versus other protective systems is likely to be more appropriate. In any case, such analysis is beyond the scope of this dissertation.

Focus Systems

Prior to military involvement in Afghanistan, IED detection and neutralization capabilities were limited, and both available systems and developing technologies focused mainly on humanitarian post-conflict demining operations. As of 1997, the main detection systems were the AN/PSS-11 and AN/PSS-12 handheld metal detectors, fielded to the Army and Marines respectively.[42] A major limitation of these systems is that they are unable to detect nonmetallic mines. Minefield marking was accomplished manually using the Hand Emplaced Minefield Marking System (HEMMS), a system deemed "ineffective and labor intensive" following use in Operation Desert Storm.[43] Mine neutralization was accomplished mainly with mine rollers attached to the front of vehicles. Rollers are not an adequate neutralization tool, as they are limited in effectiveness against more complex IEDs, such as remotely operated standoff mines which do not necessarily explode due to the pressure of a roller, and totally ineffective against mines emplaced on the side of the road outside the reach of neutralization vehicles.

Over a ten year period, anti-IED development has undergone profound changes. As of fiscal year (FY) 1997, a total of nine countermine systems were under development.[44] In contrast, three years after the end of major combat operations in Iraq, dramatic increases in research, development, and fielding related to anti-IED systems occurred. In 2006, the Joint Improvised Explosive Device Defeat Organization (JEIDDO), tasked with overseeing anti-IED capabilities in the military, received over 1,000 proposals regarding potentially useful technologies, of which 384 passed initial reviews. Of these, 240 were funded for research, and 82 systems were fielded.[45] In 2012, JIEDDO enumerated 223 stand-alone counter-IED initiatives being developed under its watch.[46]

Over the past decade, the majority of anti-IED systems have been researched and procured through avenues outside of the traditional development framework to ensure rapid acquisition and fielding. However, budget and schedule data are only available for systems that at some point enter the formal RDT&E process and end up recorded in R2 justification sheets. RDT&E data is therefore only available for ten anti-IED systems recorded in the R2s. The discussion that follows will consider those ten systems as a focal point, but will also include other key systems developed outside the formal RDT&E process since the beginning of operations in Afghanistan in 2001.[47]

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[42] Office of the Under Secretary of Defense (1997)
[43] Office of the Under Secretary of Defense (1997), p. 21
[44] Office of the Under Secretary of Defense (1997)
[45] JIEDDO (2006)
[46] GAO (2012)
[47] It is not possible to discuss all of the anti-IED systems over the last decade, both because they are so numerous, and because there is no centralized database of all such systems. However, an overview of the most important systems is presented here.

Ten systems undergoing traditional RDT&E were identified as being directly related to anti-IED and anti-landmine tasks in the 2006 budget justification sheets. By various methods, the systems are designed to perform either mine detection or mine neutralization. **Table 5.1** separates the systems into these two groups. In the table, EDIT and Scanjack, highlighted in blue, appear to be operational and ready-to-be-fielded, but have not been procured. By the usual convention used in this dissertation, yellow systems are still being developed. Two systems top $150 million in funding, are still under development, and have been so for almost two decades, a time frame that bridges both contingencies in the 21st century. Green entries have all been procured, with the caveat that the ScanEagle Unmanned Aerial Vehicle (UAV) is currently being leased from a commercial enterprise for surveillance missions, and so is not a formal procurement by the military.[48] Only one system, the Mongoose, highlighted in red, has been officially canceled.

Table 5.1 Summary of Anti-IED Systems

System Type				
Mine Detection	**Accronym**	**Total RDT&E Cost**	**Total Years of Development**	**Method**
Airborne Standoff Minefield Detection System	ASTAMIDS	254.873	22	Airborne Radar
Ground Standoff Minefield Detection System	**GSTAMIDS**	**172.015**	**19**	**Ground Radar**
Automous Mine Detection System	AMDS	112.071	13	Ground Radar
Husky Mine Detection System	HMDS	87.231	4	Ground Radar
Change Detection Workstation	CDWS	15.774	3	Imagery
Electromagnetic Wave Detection and Imaging Transceiver Landmine Detection	**EDIT**	**6.443**	**5**	**Electromagnetic Wave Detection**
ScanEagle	N/A	3.165	1	UAV Surveillance
Mine Neutralization	**Accronym**	**Total RDT&E Cost**	**Total Years of Development**	**Method**
Mongoose	**N/A**	**80.079**	**5**	**Explosive Neutralization**
Shorstop	N/A	23.575	8	Frequency Jammer
Scanjack	**N/A**	**0.959**	**1**	**Mechanical Flail**

Mine Neutralization

The three mine neutralization systems listed in **Table 5.1** accomplish their goal in unique ways. The Mongoose detonates mines with a net of shape charges. The Scanjack is a vehicular system with an attached mechanical flail designed to root out mines and IEDs. The most important system in the group, the Shortstop, provides an IED jamming capability, and is the seed of a successful effort to dramatically reduce the use of remotely-detonated IEDs by insurgents.

[48] Kaufman (2004)

Canceled and Non-Procured Systems

Of the three mine detection systems included in the 2006 R2s, one, the Mongoose, was canceled, and the other, the Scanjack, was not procured. These two systems represent relatively minor entries in the Army's battle against IEDs, and are discussed briefly first.

Mongoose

The cancelation of the Mongoose was prudent, because termination of development does not leave an urgent capability gap unfilled. Rather, the capability that the system provides is simply of a lower priority, and the cost of development, procurement, and operation and maintenance of the system is too high.

The Mongoose system fires a net of shaped charges, which explode to detonate mines, over a space roughly equal to half a football field, and was therefore best suited to clear large, highly-concentrated minefields placed under conventional warfare scenarios. Usage of the system is expensive given the broad area the net covers and the number of shaped charges expended in each firing. Furthermore, the system has no mine detection capabilities, and does not ensure that all mines within a minefield area are detonated.[49] A drawback of the system is that it actually has the potential to delay clearance efforts, since use of the system could leave shrapnel over a large area that could produce false alarms in detection systems. Given the priority of finding individual IEDs and mines in Iraq and Afghanistan, large-area clearance is not a top priority, and development of the Mongoose is at best postponable. It is important to note that the cancelation of the Mongoose did not result in a total loss of capability or technology. The shaped charge munition developed under the program was later repackaged for the neutralization of individual mines in the GSTAMIDS program, which is discussed more below.[50]

Scanjack

The Scanjack mine clearance system is an example of a ready to be fielded capability that has substitutes within the currently fielded anti-IED portfolio that can perform a similar function, such as the currently fielded Buffalo mine clearance vehicle, which is a heavily armored vehicle that rolls over IEDs to detonate them. The Scanjack utilizes flails to clear anti-tank and anti-personnel mines.[51] The Scanjack is based on a Finnish deforestation machine, and was developed by a company in Sweden. The system appears briefly in RDT&E documents as a result of Army

[49] Maclean (2003)
[50] Axelband (2011)
[51] (Buffalo Armored Vehicle n.d.)

assessment of the system in one fiscal year, totaling $0.959 million. While the Iraqi Mine Action Authority has made purchases of the system, the Army has not recorded any procurement amounts.[52]

A major development success story: Shortstop

Unlike the two mine-neutralization systems discussed above, the IED jamming systems that evolved from the third mine-neutralization system in Table 5.1, Shortstop, were able to drastically reduce, and in some geographic areas, completely eliminate the use of radio-frequency, remotely detonated IEDs against coalition forces.[53] The jamming systems that evolved from Shortstop thus represent a clear victory for the military development community.

The jammers that evolved from the Shortstop system were able to bring the Army from very crude jamming capabilities in 2002 to very sophisticated and effective capabilities by 2007. This rapid development of jamming abilities was likely due to a high level of focus on the IED problem by each of the military services. Because development had to be rapid, coordination between the services was sometimes lacking. However, while coordination and cooperation is often desirable, the lack thereof in the development of jamming systems may have been a blessing in disguise. The military services built and fielded multiple 'good enough' jamming systems rapidly, rather than refined, perfected systems developed over long periods of time. Resolution of operating conflicts and integration between jamming systems only occurred after initial system fielding. Thus, despite inadequacies in the jammers and electronic interference between the jammers and communications systems, rapid fielding likely saved many lives.

At the end of major combat operations in Iraq in 2003, emerging insurgent groups faced overwhelming disadvantages in conventional warfare capabilities in comparison to coalition forces. As a result, the IED became the preferred method of attack for the enemy. By June of 2004 IED attacks soared, with coalition forces subject to 600 attacks per month, compared to 22 per month in June of 2003. As of June 2006, an IED attack averaged 2000 per month, and at one point numbered around 100 IED attacks a day.[54]

Anti-IED jamming capabilities were inadequate to deal with the emerging threat. In 2002, the Army fielded a jamming device called the Acorn, which was fielded with a host of capability limitations. The Acorn emitted a barrage signal that jammed a wide bandwidth, had to be left on at all times, drained excessive battery life from its vehicular power source and caused interference with other electrical processes such as radio communications. More importantly, the system could only jam one

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[52] Jane's, 'Scanjack 3500' (n.d.)
[53] Shachtman (2011)
[54] Shachtman (2011)

specific receiver used in early IEDs, and could not be reprogrammed. As IED components changed, the system lost all effectiveness.[55]

The Shortstop system offered an improvement over Acorn. The Shortstop is an electronic jammer introduced during Desert Storm, and was developed to prematurely detonate radio frequency, proximity fused munitions such as artillery and mortar rounds.[56] Initial development of the system began in 1990, with usable units available in contingency storage as of 1995.[57] Efforts in 2002 resulted in a modified system that could be programmed to jam an array of signals meant to remotely detonate IEDs. Modification of the Shortstop happened quickly, and the system - renamed the Warlock Green - was fielded to Iraq beginning in March, 2003.[58]

The Warlock Green worked by detecting, recording, modifying, and rebroadcasting a triggering signal to jam remotely-detonated IEDs. The jamming process took a few seconds to complete. While the system was initially successful, as the conflict in Iraq progressed, insurgents countered the system by using low-powered triggers, such as garage door openers, that could set off an explosive in a fraction of a second, too quick for the Warlock Green jamming process to be effective. The Army rapidly modified the system to produce and field the Warlock Red to block such triggers. [59]

Two more important problems hindered the performance of early Warlock jammers. These jammers could only cover a portion of the radio frequency spectrum, and they often conflicted with other systems used by the Army and with each other. On the one hand, Warlock Green and Red had to be used together since they covered two different frequency bands that were used in different IEDs. On the other hand, much like the earlier Acorn system, they would block communication systems in convoys. Alternatively, the Warlock Green could sometimes lock on to the signal of Warlock Red, and vice-versa, jamming each other and canceling their protective properties.[60]

Partly as a result of the limitations of the Warlock systems, and partly due to duplication across the services, devices similar to Warlock Green and Warlock Red were being developed concurrently. Multiple systems were fielded rapidly in response to the ever-evolving techniques utilized by insurgents, resulting in significant gains in capability in a relatively short amount of time. Still, electronic interference between different jamming systems became a problem, and the proliferation of jamming devices reached a height in 2006, when a Navy initiative was tasked with coordinating a total of fourteen different jamming systems. Protocols were developed that allowed one jammer to

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[55] Schachtman (2011)
[56] GlobalSecurity.org, 'Shortstop Electronic Protection System (SEPS)' (n.d.)
[57] C4IEW (1996)
[58] Shachtman (2011)
[59] Shachtman (2011)
[60] Shachtman (2011)

send out its signal and then pause, allowing a jammer of a different frequency to broadcast a signal. Using this methodology, the Warlock Red and Warlock Green were packaged into a single unit.[61]

As a result of attack escalations, the military created JIEDDO in 2006 to focus military research and procurement efforts related to anti-IED systems.[62] JIEDDO initially focused on IED jammers and robots that could create a standoff capability in mine neutralization and detection. These systems were often procured through the Joint IED Capability Approval and Acquisition Management Process (JCAAMP), JIEDDO's rapid acquisition process. The goal of JCAAMP is to find and develop a system within 4 to 12 months, and deploy and assess the resulting system within 12 to 24 months.[63]

Despite the establishment of JIEDDO as an overarching development body and despite attempts to reduce signal interference between jamming systems, development efforts were still uncoordinated, likely because of the rapid acquisition philosophy employed in fielding jamming systems. The services still developed anti-IED technologies independently of JIEDDO, under organizations such as the Army Asymmetric Warfare Office, the Marine Corps Warfighting Laboratory, and the Interagency Action Group counter-IED task force. As a result of a lack of coordinated research, a wide variety of different jammers were fielded to the different services in Iraq.[64]

Still, jammers continued to increase in sophistication. The Marines' Chameleon countermeasure could cover a broad range of trigger frequencies. Meanwhile, the Warlock Duke was introduced to overcome advanced digital triggers. Unlike the Warlock Green that would send out a modified version of a detected signal, the Duke worked like the Warlock Red, in that it would broadcast a built-in jamming response that enabled a quicker, more effective response.[65]

The effort to develop IED jammers has been criticized for lacking coordination and focus. In the case of the Warlock Duke, for example, JIEDDO developed the system without full participation by the Army, so that service requirements were not fully considered in the development process. As a result, twenty proposals for configuration changes were made after the contract for development was awarded.[66] As of 2009, a Government Accountability Office audit of JIEDDO found that throughout the existence of the organization, JIEDDO had a lack of clear objectives and still did not have oversight over all anti-IED initiatives occurring in each of the services.

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[61] Shachtman (2011)
[62] GAO (2009)
[63] JIEDDO (2007)
[64] GAO (2009)
[65] Shachtman (2011)
[66] GAO (2009)

Those criticisms were valid. In the future, rapid development and fielding efforts could be improved if a responsible agency is fully empowered to coordinate and direct research efforts. But while the introduction of jamming capabilities into the field was at times chaotic, a major lesson learned is that rapid development and fielding was ultimately successful, largely because of a philosophy of quickly fielding 'good enough' systems rather than developing refined systems over long periods of time. By 2007, an embedded journalist reported that remotely detonated IEDs were 'relics' in some areas of Iraq.[67] As of 2005 ninety percent of IEDs in Iraq were radio-controlled and wireless, but by 2009 that figure was reported to be twenty percent countrywide.[68]

Another lesson to be gleaned from these successes is that allowing multiple concurrent development efforts is sometimes of utmost importance. The IED threat is likely the largest capability gap faced by the services in Iraq and Afghanistan today in terms of preventable casualties. Throwing a multitude of potential solutions at the problem may be necessary, given the high human and financial costs associated with IED attacks.

An August, 2012 GAO survey found 107 initiatives being developed by nineteen separate organizations to counter cell phone-triggered, wireless IEDs. In response to this finding, the GAO stated the following:

> While the concentration of initiatives in itself does not constitute duplication, this concentration taken together with the high number of different DOD organizations that are undertaking these initiatives and JIEDDO's inability to identify and compare C-IED initiatives, demonstrates overlap and the potential for duplication of effort.[69]

In reaction to these comments, policy makers should be wary of calls to restrict the number of technologies in development simply because the resulting systems would seem to be duplicative or redundant. Given the need for urgent readiness in a tight budgetary environment, developing and fielding a variety of similar systems, rapidly assessing how well those systems work, and then upgrading and combining the best ones for use going forward is a strategy that has been proven to work, at least in the case at hand. Each of a variety of development efforts may attack a capability gap using a different method, solve a part of the gap that the others can't, or be cheaper to procure and maintain.[70] If the capability that would be provided by any one of the systems is considered essential, a larger number of development efforts may be required in order to bring some part of the capability to the field in a timely manner. Moreover, the development of alternative technologies

[67] Shachtman (2011)

[68] Rosenberg (2009)

[69] GAO (2012)

[70] A capability gap can consist of multiple sub-gaps. Insurgencies can create different sub-gaps for coalition forces by using different frequencies or frequency forms to trigger explosion. Thus, multiple anti-IED systems may be needed to meet these different capability sub-gaps.

during concept development may also foster competition among developers of duplicate systems. Thus, multiple developments not only hedge against development failure of some systems but also encourage faster development and fielding of finished systems or can potentially drive down the unit costs of fielded systems. Effective portfolio analysis has to consider many factors including redundancy, complementarity, risk of project cancelation, and cost in providing a safety margin.

It should be pointed out that JIEDDO has not been effective at reducing the total number of IED attacks, despite success against remotely detonated, wireless versions. Because insurgents are no longer able to use radio-controlled, wireless IEDs against American troops, they have turned instead to alternative methodologies. Two primary detonation methodologies in particular are actually more primitive than wireless IEDs but not susceptible to jamming: "command wire" and "pressure plate" IEDs. Command wire IEDs are attached to a wire, and must be manually detonated from a distance. Pressure plate IEDs are triggered when stepped on or driven over.[71] While radio-controlled IED attacks were down in 2009, attacks overall were up.[72]

In the face of more primitive IEDs, a technological answer may not be the best solution to the problem. JIEDDO has three goals: defeat the device, attack the network, and train the force.[73] In 2006, JIEDDO did not fund these equally. Sixty seven percent of the budget was spent on defeat the device, 22% on attack the network, and 8% on training.[74] Rather than focusing so fully on defeat the device technologies, it has been suggested that targeting key members of the emplacement network,[75] or a more 'holistic' approach, incorporating surveillance, forensics, electronic warfare, UAV support, and other concepts, would be more effective.[76]

JIEDDO seems to have responded, at least in the distribution of research dollars over time. As of 2012, 48% of the budget went to 'defeat the device' and 37% of funds went to attack the network initiatives, with the other 15% going towards training and services and infrastructure.[77]

While it is true that the enemy has countered technology development by moving to more primitive IEDs, the reduction of remotely detonated, wireless IEDs cannot be seen as anything other than a success. That success also came quickly. To go from the use of relatively ineffective jamming systems in 2002 to an almost complete cessation of radio-controlled IEDs in 2007 – a five year span – is extremely fast when compared to traditional development efforts undertaken by the Army. The

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[71] Shachtman (2007)
[72] Rosenberg (2009)
[73] JIEDDO (2008)
[74] JIEDDO (2006)
[75] Cary (2011)
[76] Day (2006)
[77] Of the 15%, train the force accounted for 11% of the budget and staff and infrastructure accounted for 4%. JIEDDO (2010)

important lesson is that the military services did not wait to achieve perfection before fielding systems, and did not demand that systems meet a host of requirements. Rather, many systems were fielded as quickly as possible, so long as they could defeat current IED threats. Improvements to and combinations of those systems were performed following initial fielding and feedback, resulting in a group of successful, effective jamming systems.

It should be noted that despite these successes, the military was not generally good at anticipating the escalation of IED attacks in Iraq and Afghanistan, and did not have adequate systems available to soldiers immediately. As a result, despite the successes of the rapid development and fielding of jamming systems, casualties mounted in the interim while the development community reacted to events on the ground. Given that IED attacks make up the majority of casualties in Iraq and Afghanistan, this is not a trivial point, especially given the human misery and financial cost resulting from military injuries and fatalities.

The role of the traditional RDT&E process is to anticipate the use of varying technologies - whether they are primitive and established or newly emerging - that adversaries may adopt or use in the future, and to counter them with anti-IED systems preemptively. It is also important for the traditional RDT&E to develop the basic anti-IED technologies and components so that the military has the necessary tools to respond to emerging threats through the rapid acquisition and fielding process.

Mine Detection

With the successful fielding of jamming systems and a subsequent switch by insurgents to primitive, hardwire and pressure plate IEDs, detection rather than neutralization of devices has become a key capability gap. Unfortunately, mine detection has remained a stubbornly difficult problem for the military. From the formation of JIEDDO in 2006 to 2011, the rate of detection of IEDs prior to detonation remained at around 50 percent.[78] As of March, 2011, Lieutenant General Michael Oates, then director of JIEDDO, acknowledged the lack of "return on investment" on detection technologies, and specified that detecting IEDs from outside the blast range was one of the largest challenges the military faced.[79, 80]

A real-world example illustrates this point well. In July 2005, Noah Shachtman, a journalist with wired.com, was embedded in Iraq with an Explosive Ordinance Disposal team. Responding to a suspicious package, the team discovered nothing more than discarded clothes. However, returning from the investigation, the reporter's Humvee went over an artillery shell that did not explode.

[78] Cary et al. (2011)
[79] Magnuson (2010)
[80] Cary (2011)

Paradoxically, the relatively high-tech nature of the IED was probably a good thing; Shachtman surmises that a Warlock system being carried in one of the vehicles at the time jammed the device.[81] Had the IED been a more primitive wired or pressure-plate variety, casualties could have occurred.

Legacy detection systems are inadequate because they offer no standoff capability, and expose soldiers to the blast radius of a detonated IED or mine. As of 2009, a soldier reported that his unit in Afghanistan was supplied with only handheld detectors. Whenever a convoy came to a place with suspected IED placement, two marines would exit their vehicles and walk ahead to sweep for mines.[82] This not only creates a vulnerability to IED blasts, but also invites ambush by insurgents.

The Ground Standoff Mine Detection System and Airborne Standoff Mine Detection System programs are the long-standing attempts by the Army to bring a standoff detection capability to the field.[83] However, these programs have not been fielded after nearly twenty years in development. Following a delay in the development of ASTAMIDS in July of 2000, one official stated that the setback exposed a "potential Achilles heel" for the Army.[84] The sentiment has proven prescient. Interim solutions, such as the ScanEagle and Change Detection Workstation (discussed below), partially satisfy standoff detection needs but do not provide automated detection capabilities. The other systems under development by the Army, specifically the Husky Mine Detection system and the Electromagnetic Wave Detection and Imaging Transceiver (EDIT) are both close-in detection systems, in that use of the system requires operators to be within the potential blast radius of the IED. However, while the Army has found no true substitute for the ASTAMIDS program, GSTAMIDS has been supplemented and brought close to the point of fielding through partnerships with private industry and academia, and the use of COTS components in system development.

Close-In Detection Systems

The Husky Mine Detection System (HMDS) and Electromagnetic Wave Detection and Imaging Transceiver Landmine Detection system (EDIT) shown in Table 5.1 are both 'close-in' detection systems that expose soldiers to blast and ambush. These systems are representative of the main detection capabilities currently employed by the Army.

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[81] Shachtman (2011)

[82] Cary (2011)

[83] ASTAMIDS has gone through several name changes over the years. 'Airborne Standoff Mine Detection System' is actually an older designation, but is used here because as of FY 2006 and for much of its development history, this is what the system was known by. ASTAMIDS was changed to mean 'Airborne Surveillance Target Acquisition and Minefield Detection' when more requirements were added to the system, and as of 2010 the system was renamed 'Airborne Counter-Explosive Reconnaissance and Targeting System' following removal of the system from the Future Combat Systems (FCS) portfolio. Axelband (2011)

[84] Inside the Air Force (2000)

The HMDS is an example of the successful use of COTS technology and industry expertise outside of the formal Army RDT&E process to fill a capability gap. HMDS was developed in FY 2007 and consists of a ground-penetrating radar (GPR) unit attached to the front of a GOTS vehicle, the Husky. [85] The GPR unit is downward looking and is therefore most suitable for use along main routes that are accessible by the Husky.[86]

The major technological contributor leading to development of the HMDS was the Visor 2500 GPR unit, created by Niitek. The system can detect both metallic and non-metallic mines and IEDs. In 2003, the radar was demonstrated to have detection and false alarm rates "almost two orders of magnitude better than the competition."[87] In 2005, tests in Angola resulted in a 100 percent detection rate of non-metallic mines (204 of 204), and 98 percent detection of metallic mines (47 of 48).[88] The Niitek system was a leap-ahead technology that allowed the Army to go from developing basic detection technology to instead modifying the Niitek equipment for various uses.

The EDIT system is functional and as such is 'ready to be fielded', but the capability gains from the EDIT system are minimal. The EDIT handheld unit transmits energy into the ground, with buried objects storing and releasing that energy back to the detector. [89] The EDIT system is unique amongst detectors in that subsurface anomalies are mapped in two dimensions onto a graphic display, allowing classification of landmine or IED type.[90] However, because the unit is handheld, the system is of limited use in a counter-insurgency environment. The operator of the system is at risk from operating within IED blast radius, and is also vulnerable to ambush at the investigation site. Moreover, the EDIT is just one of many similar systems, including the Handheld Standoff Mine Detection System (HSTAMIDS), currently fielded by the Army. As of 2005, a humanitarian organization listed fifteen similar handheld detectors available for demining activities.[91] Still, at a total RDT&E cost of only $6.4 million, adding EDIT to the portfolio of potential countermine systems is likely prudent, particularly if the imaging technology brought to the table in EDIT can be utilized in a standoff detection system. If the system offers a marginal capability upgrade in a humanitarian post-conflict demining mission, or if the system has any potential to increase capability or decrease cost in comparison to the currently fielded HSTAMIDS system, the investment return would also be worthwhile.

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[85] Globalsecurity.org. 'Vehicle Mounted Mine Detector' (n.d.)
[86] Niitek 'Husky Mounted Detection System with VISOR 2500' (2011)
[87] Navarro (n.d.)
[88] Walls (2006)
[89] Stolar Research Corporation (2009)
[90] Geneva International Centre for Humanitarian Demining (2005)
[91] Geneva International Centre for Humanitarian Demining (2005)

Future Standoff Detection Systems

None of the mine detection systems discussed so far provide what the Army needs most – a standoff detection capability. In the latter half of the 1990s following demining operations in Iraq and Bosnia, the major goal of the Army was to create a standoff detection capability that would not expose individual soldiers to buried mines, which could find non-metallic and low-metallic mines, and would speed the process of humanitarian post-conflict demining. Key to this effort was the development of three related systems: the Airborne Standoff Mine Detection System, the Ground-Standoff Mine Detection System, and the Handheld Standoff Mine Detection System.[92]

Each of the three systems had limitations. None were effective at finding side attack mines, which attack target from the side, as opposed to from below. GSTAMIDS was rated amber for off-route mine detection capabilities, a rating that implies only partial fulfillment of a capability gap, while ASTAMIDS was rated amber for on-route detection, and, as of 2002, could not find buried mines.[93] Despite these caveats, the three systems were to provide an ever-elusive standoff capability to the Army.

HSTAMIDS is misnamed in the sense that it does not provide a true standoff capability, but it was the first system amongst the group to be fielded with a next-generation detection capability: the handheld device was developed in order to find not only metallic mines but also non-metallic anti-personnel and anti-tank mines. At the same time, the system was meant to reduce false positives caused by metallic clutter. Development of the system was a success, and the Army procured 201 HSTAMIDS systems in December 2002 to support Operation Enduring Freedom.[94]

Utilizing some of the detection components from HSTAMIDS, GSTAMIDS development began in 1992. The initial goal of the system was to automatically detect and mark metallic and non-metallic mines using a Mine Detection and marking System (MDS) mounted on a remotely controlled Mine Detection Vehicle (MDV). A manned Mine Protected Clearance Vehicle (MPCV) would then provide clearance capabilities.[95]

In 2003, the original GSTAMIDS program was canceled and replaced with GSTAMIDS FCS (Future Combat System).[96] In this iteration, GSTAMIDS was required to integrate with other FCS systems, which complicated development efforts. Interface requirements that would allow data transfer between GSTAMIDS, the unmanned ground platform it was to be mounted on, and

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[92] the Army (2002)
[93] Inside the Army (2002)
[94] globalsecurity.org - AN/PSS-14 Handheld Standoff Mine Detection System (n.d.)
[95] Pressley (2003)
[96] Globalsecurity.org – GSTAMIDS Block 0 (n.d.)

manned FCS vehicles led to significant cost growth. As of 2004, $60 million was allocated for GSTAMIDS development. However, in 2006 that number had risen to $94 million. It was estimated that 60% of the cost increase was due to changing interface requirements.[97]

In keeping with its original purpose, the GSTAMIDS suite of countermine sensors was supposed to be mounted onto an unmanned ground vehicle called the MULE (Multifunction Utility/Logistics and Equipment), in a two-vehicle configuration.[98] The goals of the GSTAMIDS FCS were loftier, however, than they had been previously. Whereas the original GSTAMIDS program called for a 'tele-operated' (remotely controlled) detection vehicle, the MULE was to carry the Autonomous Navigation System (ANS), a component allowing semi-autonomous negotiation over and around difficult terrain.[99] GSTAMIDS FCS was tasked not only with mine detection, but with mine neutralization as well. The shaped-charge munition, originally developed under the Mongoose program, was supposed to perform this function. However, use of the munition required the development of a safety release process so as not to risk friendly-force casualties, which in turn caused delays in the development schedule.[100]

Development changes and uncertainty also led to cost growth and delay. Development of the MULE occurred not only in parallel with GSTAMIDS, but also in parallel with ever-shifting goals at the higher FCS level. As a result, the GSTAMIDS program lacked a clear, fixed set of requirements. Interfacing with the MULE was a challenge, since the system had not been matured. As a result, BAE, the prime developer of GSTAMIDS, was forced to guess as to the possible interface requirements needed between the systems. As requirements did arise, they were often different from those anticipated previously. Moreover, FCS was a complex system-of-systems, with systems under development in parallel, each expected to compliment the whole. The inclusion of the MULE in the FCS program also complicated development, as changes to development needs for the MULE would often occur because a new requirement was deemed necessary for FCS overall, and the MULE / GSTAMIDS was tasked with providing it.[101] Not only did requirement changes to the MULE result in delay and cost growth, but they also drained resources from the development of the ground penetrating radar component of the system.[102]

The MULE was originally developed as a common platform allowing three operational variants - equipment transport, GSTAMIDS countermine, and an armed robotic vehicle.[103] All three variants

[97] Axelband et al. (2011)
[98] Globalsecurity.org – GSTAMIDS Block I (n.d.)
[99] GAO (2012)
[100] Axelband et al. (2011)
[101] Axelband et al. (2011)
[102] Axelband et al. (2011)
[103] Program Manager Future Combat System (2007)

were eventually canceled. The MULE Unmanned Ground Vehicle (UGV) appears to be an example of how efforts at efficiency and cost-saving can backfire when the common platform is not optimally created for any of the functions it is meant to perform. As of 2010, citing "rapidly changing threats" and an incongruence with future mission needs, the transport and countermine variants of the MULE were canceled. The ongoing armed variant of the MULE was said to account for approximately 90 percent of the research budget anyway, suggesting that the armed variant was the main thrust of the program.[104] At the time, Paul Mehney, the director of communications for the Program Executive Office, labeled the transport and counter-mine MULEs as inappropriate to current operations, but voiced approval for ongoing development of the armed robotic variant. [105,106] Yet, in August of 2011, the armed version of the MULE, which had been reconfigured and renamed the Multi-Mission Unmanned Ground Vehicle (MM-UGV), was also canceled.[107] As justification, the Army stated that "the system's Counter-Improvised Explosive Device focus and weight limited the platform's mobility."[108] Given the large budgetary share of research dollars exhausted on the armed robotic MULE, as well as the assurances by Army officials that development made sense in the current operating environment, this statement suggests the lack of a clear focus for the MULE program.

The cancelation of the MULE system was accompanied in 2011 by the cessation of the Autonomous Navigation System (ANS). Upon cancelation of the ANS, the Government Accountability Office (GAO) tasked a team of robotics experts to compare the system to six similar military and commercial systems. The team found that while it did not provide a truly unique capability relative to the other systems, the ANS had more functionality and had undergone more demonstrations and military hardening, including operating in a combat environment and protection against electromagnetic interference. Additionally, the ANS had been designed for and tested in an off-road environment, unlike some of the comparison systems.[109]

While the ANS had obvious value, it was also a long way from fielding. The Army had set aside approximately $2.5 billion for further development of the MULE / MM-UGV and ANS from 2013 to 2017.[110] Given any delays and a normal transition period from testing to fielding, this might have pushed full-scale fielding of the system into the next decade. One of the drivers behind the high cost and long development schedule of the ANS was the extra Future Combat System (FCS) related requirements placed on the system. FCS systems were required to incorporate technology to avoid

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[104] Clark (2010)
[105] The PEO is focused on equipment procurement. See https://peosoldier.army.mil/aboutus/mission.asp
[106] Hodge (2010)
[107] GAO (2012)
[108] Brannen (2011)
[109] GAO (2012)
[110] GAO (2012)

enemy detection, sensors to allow backward driving to be as fast as forward driving, a combat environment-ready GPS system, and hardened components to protect against shock and electromagnetic interference. Moreover, the ANS development effort was tasked with meeting these requirements even after the FCS program had been canceled.[111] Given that the original MULE trinity was supposed to provide standoff mine detection against insurgents, it would have made sense to reduce or eliminate some of these requirements in order to bring fielding within a timeframe to be usable in the current counter-insurgencies. Requirement reduction might also have provided flexibility that would have allowed the use of COTS components in the system. At any rate, it seems that the cancelation decision of the MULE was prudent given that system development was at risk, lengthy, and unlikely to provide a capability to troops within a reasonable timeframe. Moreover, the capabilities expected from the MULE were becoming possible using COTS systems, as discussed below.

A GSTAMIDS Contrast – the FIDO / Packbot

In contrast to the development path of GSTAMIDS, it is instructive to look at another development effort that resulted in a successfully deployed system. This development effort does not appear in the traditional Army RDT&E, likely because the system was rapidly needed in the field and never passed through traditional milestones. The FIDO / Packbot is a combination of systems that provides standoff explosives detection. The development program for the system featured two key ingredients. One, the explosives detection technology used on the system was mature and field-tested as a handheld unit prior to its use as in the standoff system. Two, the UGV platform used in the system was a COTS technology that featured a high level of functionality prior to consideration for use by the Army. As a result, the FIDO / Packbot system required only modification, not development from the ground up. Examples of the use of commercial upgrades for military purposes, like FIDO / Packbot, have grown increasingly common over the past few years.

Because the FIDO / Packbot system is made up of existing technologies and fielding schedules are tight, requirements for the system are constrained. As a result, the combined system is only expected to carry out a single mission – standoff detection of explosives. To fully satisfy standoff detection capabilities, requirements may be more complex and limit the usefulness of COTS technologies, or require that those technologies undergo major modifications. But while that may be true, in the intermediate term COTS technologies offer the ability to fulfill the most urgent aspects of capability gaps, and allow valuable testing in the field that can lead to quicker developmental upgrades later.

Returning to the example at hand, FIDO uses an Amplifying Fluorescent Polymer (AFP) sensor to detect explosives. In other molecular sensors, the strength of the signal is proportional to the number

[111] GAO (2012)

of target molecules reaching the sensor. In the case of AFP, the polymer chain carries a signal that is halted when even a single molecule of the target material strikes the chain, resulting in a highly sensitive explosives monitor with the ability to vastly outperform older technologies.[112]

The AFP technology was developed at the Institute of Soldier Nanotechnology at MIT and licensed to Nomadics, Inc. for use in FIDO bomb sniffer technology.[113] The technology was originally designed to sense TNT traces, but in 2001 sensing capabilities were expanded to find Research Department Explosive or 'RDX,' a material commonly used in mines and IEDs. The upgrade to the technology was relatively inexpensive for the government, and resulted from a $100,000 congress add-on.[114] As of 2003 FIDO was already relatively mature, and was the only sensor to demonstrate detection rates at performance levels similar to trained canines in field tests.[115] At the time, the technology was sensitive to compound concentrations 5 to 6 orders of magnitude lower than contemporary sensor technologies.[116]

In 2005, the idea to put FIDO on a UGV for standoff detection was formulated. Ten integrated systems were to be delivered in theatre on a 90-day delivery schedule. In a single half-day session, the iRobot Packbot was selected from amongst a group of candidate systems as the robotic platform for the system.[117]

Funding for integration of the systems was made available in July 2005. Cost estimates were off by a factor of two, resulting in only five prototypes being produced and fielded for testing. In theatre, technical problems were encountered, and a dedicated team of engineers was tasked with assessing performance and modifying the system in theatre. A team was formed in the US to interact with the engineers abroad and quickly solve problems.[118]

The integration and fielding of FIDO/Packbot occurred just as the Joint IED Defeat Task Force (JIEDDTF) was being reestablished formally as JIEDDO, which resulted in turnover at the top of the organization's chain of command. The transition resulted in a two month delay for procurement funding. However, initial fielding of the system occurred in July 2007 and was 25% under budget.[119] Overall, four systems were integrated and fielded in 120 days.[120]

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[112] Sherer (2007)
[113] Sherer (2007)
[114] Strategic Environmental Research and Development Program (2001)
[115] Army Communications Electronics Command, Night Vision and Electronic Sensors Directorate (2003)
[116] Strategic Environmental Research and Development Program (2003)
[117] Parmentola et al. (2007
[118] Parmentola (2007)
[119] Parmentola (2007)
[120] Berry (2008)

Several important lessons can be learned from the FIDO/Packbot system. First, in the case of both the FIDO sensor and the Packbot UGV platform, advanced standalone technical capabilities had been demonstrated in each before any integration was attempted. As a result, integration was the sole focus of development. Of course, both were also off-the-shelf components, and such an ideal situation may not present itself in 'from the ground up' Army funded development. Still, the concept of functionality before integration still applies. The second takeaway is that the FIDO/Packbot system does just enough. It doesn't feature semi-autonomous navigation or require a multi-role UGV platform. But the system does sense explosive material accurately at a standoff distance. In this case, doing one thing well and fielding rapidly is enough. In this way, the fielding of the system mirrors the rapid fielding of the myriad IED jammers discussed previously, and initial fielding can always be followed by additional research through traditional RDT&E channels later to add new requirements. In fact, as of FY2008, the Packbot and FIDO technologies were included in an applied research (6.2) 'Standoff Explosive Detection Technology' program, suggesting further upgrades are indeed on the horizon.[121] A third lesson from FIDO/Packbot is that, at least in the area of unmanned ground vehicles, COTS items are an important source of potential systems. To take one example, the iRobot corporation is developing a small 10 kg UGV, a 150 kg class Warrior heavy battlefield robot, and the 'Sentinel' program, funded by the Army's Small Business Innovation and Research (SBIR) Program, which allows for the control of multiple robots by a single operator and coordinates semi-autonomous robots using intelligent navigation.[122] Many of these proposed systems provide functions that mirror the capabilities expected from the GSTAMIDS program.

To illustrate the point further, consider a sample of UGVs included in a 2011 analysis-of-alternatives[123] for procurement. While the study did not consider all UGVs, it provides a useful sample of currently available systems. The sample UGVS are presented in While the systems in **Table 5.2** are not comparable in complexity to major aircraft, the relationship between liberal use of off-the-shelf components and successful fielding that Perry (1975) praised in the development of the F-16 apply to the list of UGVs as well.While the systems in **Table 5.2** are not comparable in complexity to major aircraft, the relationship between liberal use of off-the-shelf components and successful fielding that Perry (1975) praised in the development of the F-16 apply to the list of UGVs as well.

Table 5.2. Standard color-coding of the table indicates the development outcome of the system. Every system except for one, the canceled MULE, is either a COTS system, or was developed in collaboration with academia (Carnegie Mellon in particular).

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[121] Reago Jr. (2008)
[122] Defense Update.com - Packbot Tactical Robot (n.d.)
[123] Kilitci et al. (2011)

While the systems in **Table 5.2** are not comparable in complexity to major aircraft, the relationship between liberal use of off-the-shelf components and successful fielding that Perry (1975) praised in the development of the F-16 apply to the list of UGVs as well.

Table 5.2 - Sample of UGVs by Development Source

System Name	Status	Development Category
Crusher	In-development	Carnegie Mellon[124]
Dragon Runner	Fielded	Carnegie Mellon / Military[125]
Gladiator	In-development	Carnegie Mellon[126]
Load lifter	Fielded	COTS platform / military equipment[127]
MarcBot	Fielded	COTS[128]
MDARS	Fielded	COTS components[129]
MULE	Cancelled	Traditional RDT&E Development
Packbot	Fielded	COTS
Talon	Fielded	COTS[130]
Throwbot	Fielded	COTS[131]

Source: All status information from JANE'S

Autonomous Mine Detection System

The Autonomous Mine Detection System (AMDS), alternatively referred to as the Autonomous Mine Detection Sensors program in early budget justification sheets, is a prime example of how COTS technologies have become an integral component of an Army development program.

Like GSTAMIDS, the AMDS effort was expected to use detection technologies originally developed under HSTAMIDS and incorporate Ground Penetrating Radar.[132] Unlike GSTAMIDS, the AMDS system is envisioned as a man-packable size UGV.[133] For a two year period beginning in FY 2002, the AMDS program was supposed to develop mine detection sensors. The sensors would be integrated onto a robotic platform beginning in 2004, with a demonstration of the technology

[124] National Robotics Engineering Center (n.d.)
[125] Office of the Under Secretary of Defense, Acquisition, Technology and Logistics, Portfolio Systems Acquisition, Land Warfare and Munitions, Joint Ground Robotics Enterprise. (2006)
[126] Globalsecurity.org - Gladiator Tactical Unmanned Ground Vehicle (n.d.)
[127] Globalsecurity.org - Remote Transport System (n.d.)
[128] Applied Geo Technologies (n.d.)
[129] Carroll (2003)
[130] O'Rourke (n.d.)
[131] Recon Robotics (n.d.).
[132] Project Manager Close Combat Systems (n.d.)
[133] Johnson (2009)

expected in FY 2007.[134] However, more recent RDT&E documents describe the AMDS program as a new development effort, and data shows milestone A (an early milestone in RDT&E development policy that indicates entry into system technology development) for the program beginning in FY 2009, with development currently ongoing. As opposed to the FIDO / PACKBOT, AMDS is a much more technologically complex effort tasked with developing "aided target recognition algorithms for autonomous detection of anti-personal mines"[135] As such, it is important to note that while COTS components can be utilized, the AMDS research effort is likely to require a high level of technological innovation, and thus a relatively lengthy development schedule.

As it currently stands, the AMDS program illustrates the lessons learned by the Army over the past years. Unlike GSTAMIDS, which is tied to a particular vehicular platform, AMDS is focused more specifically on 'novel sensors and data processing algorithms' that can be integrated onto UGV platforms in the future. Plug-N-Play capabilities are a stated primary goal of development.[136]

The AMDS system also seeks to take full advantage of newly available technology. Although it is not stated by Army officials, one can surmise that the program was 'reset' because mature COTS systems have made some of the development and integration efforts previously needed under AMDS unnecessary. As it currently stands, AMDS is now a Niitek Visor GPR integrated onto Packbot and Foster-Miller Talon UGV platforms.[137]

On July 17th 2012, the 'Automated Mine Detection System,' assumed to be an alternative designation for the AMDS, was demonstrated at the Robotics Rodeo, which allows vendors to showcase new technology to the military. Hopefully, the demonstration indicates that long-delayed standoff detection capabilities are on the near-term horizon.[138]

ASTAMIDS

Unlike some of the other capability gaps identified previously, airborne standoff detection options have not been forthcoming in a myriad of forms from government, academia, or private industry. Whereas the ground vehicle-based Autonomous Navigation System was one amongst six other viable systems-under-development, the Army's in-development aerial detection system, the Airborne Standoff Mine Detection System, does not have near-ready substitutes. ASTAMIDS is not a candidate for rapid development, either, due to the inherent technological difficulties of providing a high probability of detecting mines and IEDs, at greater distances in the air as opposed to the

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134 Team C4IEWS (2002)
135 Team C4IEWS (2002)
136 Few et al. (2010)
137 The Talon is another COTS UGV platform, similar to Packbot. Niitek (n.d.)
138 Williams (n.d.)

ground. There are likely to be few COTS or GOTS systems that can adequately perform the functions expected of ASTAMIDS, while development is likely to be relatively expensive and lengthy.

As discussed above, part of the reason for the failure of GSTAMIDS was a requirement for semi-autonomous navigation to negotiate rough terrain in Afghanistan. Unlike Iraq, Afghanistan lacks the transportation infrastructure to facilitate movement of ground vehicles and UGVs. The IEDs in Afghanistan are also markedly different from those encountered in the early stages of the counterinsurgency in Iraq. Rather than being remotely detonated, IEDs are largely of the pressure-plate variety, exploding when weight is applied to the device, or hard wired and manually detonated. Explosives are often formulated using fertilizers, and may lack metallic components altogether.[139]

These factors suggest that an aerial detection system would fill an important capability gap for the military. ASTAMIDS is an airborne sensor package intended for attachment to a UAV, and is being developed to detect metallic and non-metallic surface and shallow buried mines.[140] As of 1994, ASTAMIDS was expected to be fielded in FY 1999. At the time, detection capabilities were limited:

> The detection of obstacles ahead of actual encounter provides information to the maneuver commander in time to bypass or breach the obstacle. In the near to mid-term, the COE has only the AN/PSS-1 1 and AN/PSS-12 Mine Detectors which detect only metallic components of mines. The vehicle mounted mine roller is not effective for detecting double impulse, magnetic fused or standoff mines. In the far-term, the Aerial Standoff Minefield Detection System (ASTAMIDS) will be fielded in limited numbers (budget constraints). Planned advanced technology demonstrations include the Close-in Man Portable Mine Detector and Vehicular Mounted Mine Detector.[141]

As of May 1996, the Defense Technology Area Plan listed the AN/PSS-12 handheld detector as the current countermine baseline system. ASTAMIDS was expected within five years along with an interim ground vehicle system. HSTAMIDS and GSTAMIDS were to be fielded in ten years.[142]

At the time, the Army was wisely considering many configurations of the system in order to try to ensure successful development. Two competing versions of ASTAMIDS – from Northrop Grumman and Raytheon, respectively - were being pursued at the same time.[143] The Northrop

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[139] Shachtman (2009)
[140] Office of the Under Secretary of Defense (1997)
[141] Here, 'COE' stands for 'common operating environment. Army Science Board (1994)
[142] Department of Defense (1996)
[143] Aerospace Daily (1997a)

Grumman version was deployed to Bosnia for testing in August of 1997.[144] However, in December of 1997 it was reported that test results were poor for both systems. As a result, two additional system variants, one from the Defense Advanced Research Projects Agency, and one from the Science and Technology Institute (STI) – part of the Universities Space Research Association, were also included for evaluation. Results were again underwhelming, and funding for a transition of the program to Engineering and Manufacturing Development (EMD) was canceled in favor of returning ASTAMIDS to "technology base work."[145]

The reevaluation of ASTAMIDS represented a major blow to the Army's expected future capabilities. In earlier Department of Defense documents, ASTAMIDS was expected in FY 1999. As of FY 2000, the Defense Technology Area Plan still listed the AN/PSS-12 handheld detector as the baseline countermine technology. The IMVDD – a close-in detection configuration similar to the HMDS – joined it. GSTAMIDS and HSTAMIDS were now expected five years out (by 2005), but fielding of ASTAMIDS was listed as ten years away (by 2010).[146]

In reality, the ASTAMIDS system was originally suited for use in conventional warfare or in humanitarian demining operations, but not in the new contingencies that would soon arise. ASTAMIDS was designed to achieve a 75% detection rate of antitank mines, adequate to detect minefields and therefore of use primarily in conventional warfare involving large troop movements.[147] The system was likely much farther away from being an adequate solution in a counterinsurgency, since ASTAMIDS was not suited to find individual mines or IEDs. After a brief hiatus in development, 2002 combat operations in Afghanistan brought renewed interest to ASTAMIDS. At the time, it was suggested that development of ASTAMIDS was stalled partly because the Army canceled its host UAV, the Hunter system, leaving ASTAMIDS without a platform. In this iteration, ASTAMIDS was scheduled to be outfitted to another under-development UAV, the Shadow Tactical UAV (TUAV). The Army also tried to speed development by soliciting the use of COTS components where applicable.[148]

In 2003, the FCS program staff singled out ASTAMIDS as capable of meeting the Army's Reconnaissance, Surveillance, and Target Acquisition / Laser Designation (RSTA/LA) requirements. In April 2005, the requirements of the ASTAMIDS program were therefore increased to include these additional capabilities.[149]

[144] Aerospace Daily (1997b)
[145] Aerospace Daily (1997a)
[146] Department of Defense (2000)
[147] DeRiggi (1997)
[148] Tuttle Aerospace Daily (2002, p. 3)
[149] United States Department of Defense (2008)

While ASTAMIDS is capable of providing an RSTA/LA capability and combining system requirements may be efficient in the long run, it is also likely that doing so delayed system fielding. The added capabilities introduced a host of subcontractors to the development process. **Table 5.3** displays each of the additional capabilities to be developed, the companies tasked with developing them, and the dollar amounts allocated for each, as of FY 2008.

Table 5.3 - Additional ASTAMIDS Requirements, Developing Corporations and Allocated Funding

Task	Company	Dollar Value (Millions)
Reconnaissance, Surveillance, and Target Acquisition	DRS Technologies	$23.8
Eye-safe laser designator/rangefinder	Fibertek	$6.7
Camera and lens	Apogen Technologies	$10.6
ASTAMIDS software	ARETE Associates	$2.7

Source: Inspector General, United States Department of Defense (2008)

Over the course of development, ASTAMIDS again transitioned to insertion on a new platform when the Tactical Unmanned Aerial Vehicle was scrapped in favor of the vertical take-off and landing Fire Scout UAV.[150] As a system meant to network with other FCS systems, the Fire Scout also came with added capability requirements, including standoff chemical, biological, radiological and nuclear (CBRN) detection, meteorological data for the non-line-of-site (NLOS) cannon, manned / unmanned teaming, and wideband communications relay.[151]

The added delays to ASTAMIDS are at least partly due to delays in development of the UAV system it was to be hosted on. As of 2008, a low-rate initial production (LRIP) decision for ASTAMIDS was expected in 2009. However, the LRIP for Fire Scout was due in 2013 as a result of "delay in developing the communication, network, data link, and computer components to link the Fire Scout with the FCS system-of-systems."[152]

As of December 2010, reports were that ASTAMIDS had done well in tests and could "detect simulated … IEDs".[153] Individuals familiar with the program state that the system demonstrated a 90% detection probability for buried mines and IEDs.[154] Despite these positive reports, there is

[150] DoD (2008)
[151] Hannah et al. (2008)
[152] DoD (2008 p. 8)
[153] Defense Daily (2010, p. 9)
[154] Axelband et al. (2011)

currently no record of any acquisition of ASTAMIDS, although JIEDDO apparently plans to field the system at some point.[155]

Over the course of the development of ASTAMIDS, the Hunter, TUAV, and Fire Scout – and given that the Fire Scout was canceled in 2011 - another future candidate platform will all have been associated with ASTAMIDS.[156] The number of ASTAMIDS systems to be fielded is likely to be relatively limited, and as a result it might make more sense to get an initial spiral of the system, with only the most essential detection capabilities, into the field on whatever transport platform is established and available. Once the system has proved its worth, integration onto other systems can take place, once those platforms are mature enough to ensure fielding. This strategy would save the time and money needed to repeatedly integrate ASTAMIDS into systems that were ultimately canceled.

The first iteration of ASTAMIDS was already complicated, and four separate corporations were unable to mature the system along the development pathway. Given the military need for the system in Afghanistan, simply developing the system in its most basic form in a timely manner is already a tall order. Adding further capabilities - and other sub-developers under the main contractor – does not seem to sufficiently focus on the main goal of timely fielding.

Current Standoff Capabilities

Without automatic standoff detection capabilities, systems such as the Change Detection Workstation (CDWS) and ScanEagle UAV are examples of the interim standoff detection capabilities that the Army currently employs. Aerostat blimps, fitted with cameras capable of wide area surveillance, are the Army's main standoff surveillance and detection systems. A small number of aerostats were installed over Kabul at the time of the troop surge in December 2009. Since that time, sixty more were placed in Afghanistan, with a plan to double that number as of January 2011.[157] These systems are important reminders that when delays in systems such as ASTAMIDS occur, the Army needs to quickly recognize a chronic capability gap in the making and take steps to preemptively fill it using alternative systems.

As examples of surveillance systems, the CDWS and ScanEagle are important components of the Army's system portfolio. However, the capabilities they provide are not a direct substitute or adequate replacement for the ideal capability that the Army expects ASTAMIDS to provide. ScanEagle is representative of the UAV surveillance systems that can spot IED emplacement, while

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[155] Axelband et al. (2011)
[156] Phillips (2011)
[157] Whitlock (2011)

the CDWS compares images to find evidence of change of the scenery that might indicate buried IEDs. Neither of the systems provides an automated mine detection capability.

Both the CDWS and ScanEagle are based on COTS technology that has been modified for military use. Both systems were also fielded quickly. The CDWS was recorded in RDT&E documents for three fiscal years, while the ScanEagle system only received funding in one fiscal year.

The CDWS system began development in 2002.[158] The core of the system is the Change Detection Server (CDS), which automatically captures still images from photographs or video and creates 'mosaics' – a seamless panoramic layout - from those images. For example, the mosaic may display a full stretch of roadway compiled from individual images of segments of the road.[159] In its most basic format, the CDS puts two images side-by-side, for example the same road on two consecutive days, and an operator is tasked with attempting to manually identify indications of IED placement across the images.[160] Research efforts initiated in 2005 added software to the system in order to provide some automatic indications of landmine and IED placement.[161]

The CDS can be configured along with the CDWS hardware, but can also be used as a software-only installation on a COTS hardware system. The system also utilizes COTS software to create image mosaics.[162]

The ScanEagle UAV is an example of a low development cost, quick turnaround COTS system that provides a key capability to the Armed Forces. The system is being leased by the military from Insitu, the developer of the system.[163]

The ScanEagle is a medium altitude, long endurance UAV.[164] The system is especially useful in counter-insurgency operations because it weighs only forty pounds at launch, does not require a runway for launch or retrieval, and can operate continuously for more than 24 hours.[165] Because the system features a catapult launch and a 'Skyhook' near-vertical recovery mechanism, the ScanEagle is ideal for use in unimproved areas.[166]

In 2008, Insitu (the developer of ScanEagle) and Boeing (which acquired Insitu in July of that year) developed the as-yet smallest synthetic aperture radar (SAR) payload for the ScanEagle, a two pound

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158 Observera (n.d.)
159 Observera (n.d.)
160 Axe (2010)
161 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (n.d.)
162 Observera (2005)
163 Inside the Navy (2012)
164 Collier et al. (2008)
165 Insitu Incorporated (2010)
166 Alkire et al. (2010)

sensor called NanoSar. This new technology allows surveillance in an adverse-weather environment. [167]

ScanEagle provides a frontline surveillance capability for small military units because of its size. Larger, Army engineered systems like Hunter, Predator, and Pioneer are fielded in limited numbers, and are therefore not suited to on-the-spot counter-IED missions. On the other hand, small UAVs such as the Dragon are too small to carry both imaging and radio-frequency IED-detecting payloads.[168]

Cost is an important consideration in usage of the ScanEagle. Larger UAVs are very costly to operate, especially as more capabilities are added to these systems and their weight increases. On the other hand, the maker of the ScanEagle, Insitu, estimates that the system can accomplish 80% of the Predator's missions at 5% of the cost.[169]

Systems like ScanEagle and the CDWS are vital because they provide some capabilities for IED detection at a low cost and on a rapid fielding schedule. However, they are unable to replicate or replace the capabilities that remain unfulfilled because of the delay in fielding of ASTAMIDS.

Lessons Learned

In the area of anti-IED systems, several lessons arise from the development efforts discussed above.

Rapid development, deployment, and upgrade following fielding are viable strategies when a capability needs to be provided quickly. Of course, this can only occur when technology readiness is at a level high enough to allow fielding. However, despite criticism leveled at JIEDDO and the jamming development effort in general, the rapid development of jamming systems should be viewed as a success given the drastic drop in radio-controlled, wireless IED attacks.

The analysis of the anti-IED portfolio is illustrative of the benefits of a safety margin within the fundamental capability portfolio. The Scanjack and EDIT systems were amongst the least expensive in the anti-IED portfolio, as well as amongst the overall group of 17 focus systems from Table 4.1. Development of the Scanjack and EDIT systems resulted in $960,000 and $6.443 million in development costs, respectively, and could provide a cheap safety margin within the anti-IED portfolio. Of course, if the cost of these systems had been higher, it would make sense to review their continued development.

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[167] Previous SAR systems weighed in at around 30 pounds. See: Egan (2011)

[168] The Dragon is almost solely used with small cameras. Unmanned Aerial Vehicle-mounted High Sensitivity RF Receiver to Detect Improvised Explosive Devices. See: Griffith (2007)

[169] Elder (2003)

The jammers in this portfolio review in particular suggest that 'redundancy' and the coincident development of several similar systems is not necessarily an indication of inefficiency, although that may exist when agencies or services do not coordinate their respective development efforts. In this case, the development of a large number of similar systems allowed partial fulfillment of a larger capability gap in a timelier manner than would be possible if a single, unique development effort tried to provide a total solution to the entire IED problem prior to fielding. Such a deliberate development policy would be unsuited to react to a quickly evolving insurgency. Portfolio managers should therefore heed this case when determining how to cut the development budget. If a particular capability gap results in high human and economic costs to the Army, it may save money in the long run to implement several concurrent development efforts and attempt to close the gap sooner. In these cases, rather than attempting to cut down on 'redundancy' within the development portfolio, it may be more efficient to encourage competition between concurrent development efforts in order to encourage faster fielding.

COTS systems are increasingly viable in filling capability gaps. The Army appears to have learned this lesson through the use of COTS components in systems and through forums, like the Robotics Rodeo, that allow interaction between academia, industry, and government.

In many key cases, COTS components and incremental fielding and development cannot replace traditional RDT&E development processes. In the case of ASTAMIDS in particular, no COTS or GOTS system was available that could adequately produce the capability the Army needed. As a result, there were no near-ready systems that could act as near substitutes for ASTAMIDS and that could be rapidly acquired and fielded. In the end, ASTAMIDS and systems like it need to be developed through traditional RDT&E routes. It is vital, then, that the Army's RDT&E procedures are improved to reduce the development failure rate and the funds lost due to cancelation.

Standoff mine detection was a key component of the anti-IED portfolio, but unfortunately high-capability systems in this area were also the most likely to be canceled, which is not surprising given that these systems (ASTAMIDS and GSTAMIDS) were the most challenging to develop. Given that fact, the development process should be guided by the principle that in general, simpler is better. In the case of GSTAMIDS, developing a semi-autonomous robot is hard enough; adding other capability requirements such as equal backward and forward speed and hardening against electronic interference to the system only delays fielding. While the hardening requirement may be useful in a contingency against technologically advanced adversaries, it is not needed in Iraq or Afghanistan now or in the near future. This requirement could only serve to delay the fielding of a system that was needed urgently. Similarly, the difficulties of developing a high rate of detection of IEDs from the air in ASTAMIDS are self-evident without adding additional requirements to the system. Moreover, concurrently developing and canceling UAV platforms for ASTAMIDS adds delay in integration. While it is important in the long run to provide high-quality systems that close capability gaps, that goal needs to be balanced by the need to quickly field systems in order to provide some capability in the near term. Going forward, system portfolio management should include explicit calculations that quantify the tradeoff between filling more capability gaps or filling individual capability gaps better versus bringing the most needed aspect of the capability to the field faster.

Finally, it should be noted that technology was often transitioned from canceled programs into new efforts. The Mongoose produced technology that ultimately continued development under GSTAMIDS. Similarly, although the GSTAMIDS program was also canceled, much of the radar technology used subsequently in the HMDS was developed under GSTAMIDS.

Chapter Six - Small Arms Portfolio Review

Individual and crew-served weapon systems under development in fiscal year 2006 fall into two distinct camps. One group of systems was meant to introduce novel capabilities to the soldier in the form of new types of lethal rounds or combination weapons that could fire more than one round type. These systems were often expected to provide not only more comprehensive lethal capabilities but also a reduced weight over the weapons they would replace. The other group of systems had a single primary goal of providing weight reduction when compared to existing systems.

A total of seven developing small arms were identified as belonging to the individual and crew-served weapons category. These are listed in **Table 6.1**. Systems in the table are listed from earliest development initiation to latest, and are color-coded as previously described– red entries were canceled, yellow still in development or in operational assessment, blue have ceased receiving RDT&E funding but have not yet been procured, and green are in limited initial procurement.

Column two in **Table 6.1** presents the legacy system that the new weapon was meant to replace. Thus, the M240L and LWMMG are both potential replacements for the legacy M240B system. Column three shows the specific function that the new weapon was meant to fulfill, while column four shows capabilities the Army hoped to gain from each of the under-development weapons. Weight reduction is obviously a primary concern for the Army, as five of the seven systems had weight reduction as a goal (bolded in column four), with two of the five development efforts having the sole goal of weight reduction when compared to legacy systems. The final column of the table presents the current status of the development effort. So, reading across the first row of the table, one can see that the Objective Individual Combat Weapon was meant to replace a host of small arms (the M4 carbine, M16 rifle, M249 light machine gun, and the M203 single shot grenade launcher). The weapon was meant to function as a traditional carbine, but with a new smart-munition, exploding shell munition capability built in. Clearly, the weapon was supposed to fill some important capability gaps. It was meant to hit hiding (defilade) targets with the smart-munition capability, provide a combination weapon to troops to reduce load, and be lighter than the M4 or M16. Unfortunately, the system was ultimately canceled.

Table 6.1 – Summary of Small Arms Systems

System Name	Replaces	Function	Capabilities Provided	Development Result
Objective Individual Combat Weapon (OICW)	M4,M16,M249 and M203	Carbine / Smart Munition Launcher	Defilade Targets/ Combo Weapon/ **Weight Reduction**	Canceled
Advanced Crew Served Weapon (ACSW)	M240B,M249, M50 and MK19	Heavy Machine Gun / Smart Munition Launcher	Defilade Targets/ Combo Weapon/ **Weight Reduction**	Canceled
Anti-Material Payload Rifle (XM109)	M82	Anti-Materiel Sniper	Increased Distance / Increased Lethality	Not Procured
M240L	M240B	Medium Machine Gun	**Weight Reduction**	Limited Initial Procurement
Lightweight Machine Gun (LSAS LMG)	M249	Light Machine Gun	**Weight Reduction**	In Development
338 Norma Magnum Lightweight Medium Machine Gun (LWMMG)	M240B	Medium Machine Gun	**Weight Reduction /** Longer Distance	Limited Initial Procurement
Counter Defilade Target Engagement System (XM25)	M203	Defilade Smart Grenade Launcher	Defilade Targets	In Development

What stands out in **Table 6.1** is that all of the systems under development in FY 2006 are either in the initial stages of fielding as of FY 2013, or still in development, and that the three oldest systems are either canceled or not procured. None of the systems are being fielded at a rate commensurate with full rate production. On its face, this might mean that the Army is unable to use these systems to meet requirements in a timely manner, if at all.

Digging deeper into the three non-procured systems, it is clear that not all of the cases are equal. The XM109, a 25mm sniper rifle, was developed beginning in FY 2000 for use against hard targets, with armor piercing capabilities being a main goal.[170] In 2006, the XM109 was put into a pool of development alongside other potential sniper rifles in a program titled the 'Anti-Material Rifle Congressional Program'.[171] The other systems under development and under consideration for fielding in the congressional program were a lightweight variant of the M107 .50 Caliber (12.7mm) sniper rifle, and the XM500 .50 Caliber sniper rifle.[172] Following the competition between the systems, no evidence could be found of fielding of the XM109 by the military. In this instance, it appears that the weapon can be said to be 'ready to be fielded' – it appears to work, but was simply not chosen for procurement.[173] Such a development outcome cannot be judged a failure, since the Army was able to give itself one more option in fulfilling an anti-material sniper capability, at a relatively low RDT&E cost of merely $9.05 million. Depending on total budget, development of the system is a potentially prudent course of action for two reasons. First, the 25 mm round fired by the sniper rifle provides significantly more lethality than a .50 caliber round. As such, even if the XM109 is not necessary in a counter-insurgency environment with little in the way of hard targets, it could be quickly procured in the event of warfare with more sophisticated enemies. Second, if the XM109 were to cost less to procure, operate and maintain than comparable systems, then the savings in procurement could result in savings that are more than enough to compensate for system RDT&E costs. As such, it would be a mistake to consider a system such as the XM109 as merely 'redundant' without first taking full consideration of the capabilities and costs of the developed and fielded system. It is likely that little would be gained from the cancelation of this type of system in the future, given its low development costs.

The cancelation of the Advanced Crew Served Weapon and Objective Individual Combat Weapon on the other hand, represent a significant inability to meet Army capability gaps. Both systems were meant to replace traditional guns - the .50 Caliber machine gun in the case of the ACSW and the standard-issued carbine in the case of the OICW. At the same time, a 25 mm smart-munition was meant to be integrated into each weapon. The smart-munition would replace traditional grenade launchers, with the soldier using a laser rangefinder to fix a distance to the target. Upon firing, the 25 mm rounds were programmed to fragment just beyond the distance calculated, in order to hit concealed (defilade) targets behind a barrier or inside buildings.[174] The use of a smart-munition

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170 'XM109 Anti-Materiel Payload Rifle (AMPR),' globalsecurity.org (n.d.)

171 'XM109 Anti-Materiel Payload Rifle (AMPR),' globalsecurity.org (n.d.)

172 Lee (n.d.)

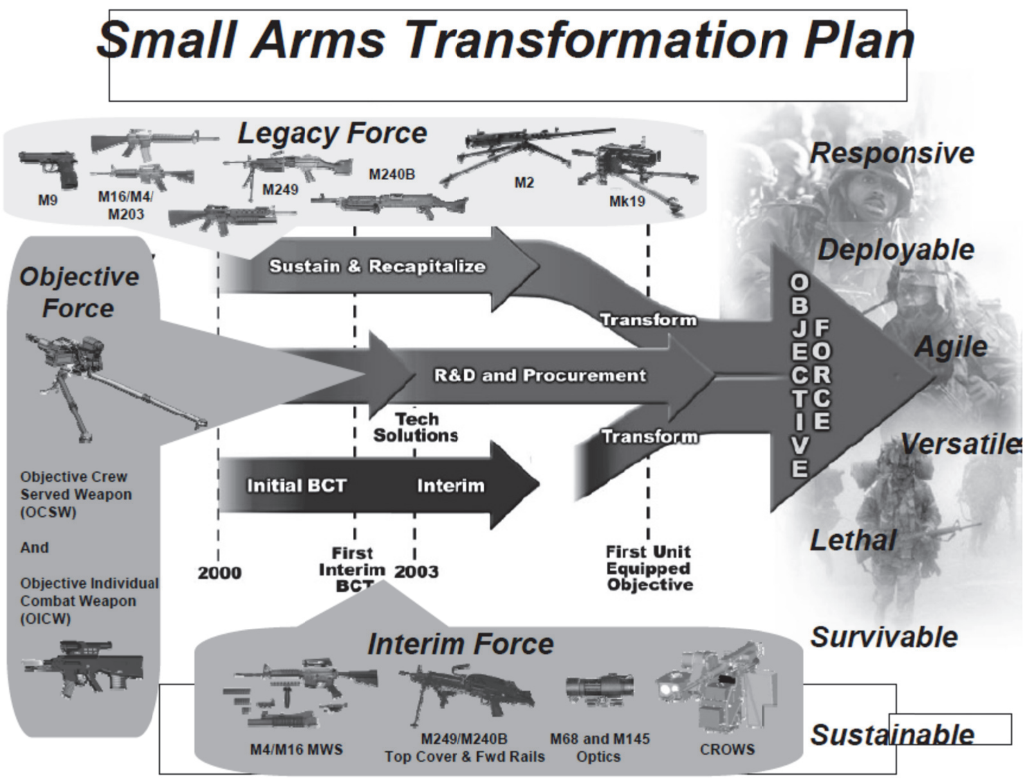
173 The Jane's database lists this system as 'in use' by the U.S. military. If it is, it is in amounts too small to be listed in Army procurement documents, which lists amounts as little as 232 (the procurement level for M107 sniper rifles in FY 2013 – see http://asafm.army.mil/Documents/OfficeDocuments/Budget/BudgetMaterials/FY13/pforms//wtcv.pdf). No purchases of the XM109 appear in government contracts information.

174 So, for example, if an insurgent were hiding behind a barrier, the weapon could calculate the distance to the barrier and then fire just beside it. The air-bursting munition would explode just beyond the distance previously calculated and harm the insurgent from the side. Defense Update (2007)

required development of electronic components in the weapon. The OICW was to include laser rangefinder, target tracker, combat identification and a laser pointer, amongst other features.[175] Both weapons were also meant to reduce recoil and weight over legacy systems.[176]

As of 2001 the ACSW and OICW were the centerpieces in an ambitious plan by the Soldier Weapons Project Manager to transform small arms in the future. As **Figure 6.1** shows, the ACSW (at the time designated the 'Objective Crew Served Weapon', or OCSW) and OICW were meant to replace a host of legacy systems, including hand guns, carbines, light, medium and heavy machine guns, and grenade launchers. These legacy systems are shown at the top of **Figure 6.1**. Interim development efforts, such as rails for the M249 and M240B and small arms optics (shown at the bottom of **Figure 6.1**), are relatively less ambitious and meant merely as temporary improvements prior to the fielding of the 'Objective Force' ACSW and OICW systems.[177]

Figure 6.1 - Small Arms Transformation Plan (2001)



Source: US Army Tactical Command[178]

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[175] Webb (2002)

[176] 'Advanced Crew Served Weapon', Globalsecurity.org (n.d.)

[177] Note that in the figure, the ACSW is referred to by an alternative name, the 'Objective Crew Served Weapon' (OCSW).

[178] Audette (2001)

Objective Individual Combat Weapon (OICW)

The OICW began development in December of 1993.[179] In 1998, an Advanced Concept Technology Demonstration (ACTD) for the system revealed serious obstacles to further development.[180] These were documented extensively in a case study by Erik C. Webb, the source of much of the information related to this system as discussed below.

The Army expected the OICW to be lightweight. In fact, the threshold weight requirement for the system was fourteen pounds or less, with an objective (ideal) weight requirement of less than ten pounds. This was a significant weight reduction compared to legacy M4 and M16 systems, which weigh approximately 19.5 pounds. However, it was clearly going to be a challenge to meet either of those weight targets. At the time of the 1998 ACTD, the OICW prototype weighed in at 21 pounds, even though direct view optics, laser designator, and other sighting components were not included on the prototype.[181]

At the same time, the weapon was not meeting other requirements. The smart-munition round did not meet lethality requirements because of insufficient burst radius of the munition round, while there was a significant lack of accuracy associated with the prototype. At the time of prototyping, Webb estimated the air-bursting round to be at a technology readiness level (TRL) of three, at an analytical and experimental 'proof of concept' stage. Currently, according to the Department of Defense, systems are to be at TRL 6 prior to entering the Engineering and Manufacturing Development (6.5) phase.[182]

At the time of the ACTD, it is apparent in hindsight that the dual goals of the OICW development effort were incredibly ambitious while at the same time conflicting with one another. The system had to weigh less than previous weapons, while at the same time incorporating a new type of lethality capability in the form of a smart-munition - with all the electronic sub-components necessary therewith - alongside a carbine. To compound the problem, technology readiness for the new air-burst munition was in the nascent stages of development, far below where it should have

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[179] DOD (2005)

[180] At the time, ACTDs were known as 'Advanced Technology Demonstrations' (ATDs). The more modern terminology is employed here to avoid confusion.

[181] Webb (2002)

[182] Technology Readiness levels assess the maturity of evolving technologies, and run from a TRL of 1, where scientific research is transitioned to applied research, to TRL 9, a designation given to systems which are proven through successful mission operations. TRL 6 indicates that a system model or prototype has been demonstrated in a 'high-fidelity laboratory environment' or 'simulated operational environment.' DOD (2011)

been based on the military's own recommendations. Considering these facts, Erik C. Webb, in his 2002 case study, warned that these risks might lead to program termination.

Later in 2002, the OICW again failed to meet a weight requirement; as a result, the development effort was split into increments, with the XM8, a lightweight carbine, to be produced as increment one. In 2003, it was decided to develop two increments in parallel – the previously mentioned increment one carbine and the XM25 air-bursting system as increment two.[183] Presumably, these two increments would be developed without the immediate constraints of integration between the two increments into a single system, thus easing some of the requirements on the system.

In 2004, increment one for a lighter weight weapon was expanded beyond the lightweight carbine to include three additional distinct weapon types. This decision came about despite the risks in development discussed above, and despite the fact that program documentation never discussed the need for a family of lightweight weapons.[184] This course of action could have been reasonably expected to increase cost growth in the development process, and should have come with an acknowledgment that fielding of increment one would have to be delayed, even if requirement changes did not affect the fielding schedule of increment two, which was to be developed concurrently.

As of May 27, 2005, a Department of Defense audit found incomplete program documentation, lack of notification that the OICW was potentially a major defense acquisition program of Acquisition Process Acquisition Category One (ACAT I – in other words a Major Weapon System), and an uncertain acquisition strategy associated with the OICW.[185] The overall program was canceled in November 2005.[186]

The difficulties associated with development in the OICW program and the changes in system requirements are reflected in the schedule slippage that occurred for the program. **Table 6.2** shows the planned schedules for development in three fiscal years (2000, 2005, and 2007), shaded from darker to lighter. The major milestones of system development are highlighted in the table. Milestone B approves entry into the Engineering and Manufacturing Development phase, while Milestone C approves entry into the Production and Deployment (P&D) phase.[187]

Table 6.2 shows plans for the combined weapon (OICW) on lines one through eight, as well as the revised schedule planned for development of the separate increments on lines nine through sixteen

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[183] DoD (2005)
[184] These were, respectively, a carbine, special compact weapon, designated marksman weapon, and light machine gun. DoD (2005)
[185] DoD (2005)
[186] Murdoch online (2005)
[187] ACQuipedia (2012)

and lines seventeen through twenty, respectively, with the XM8 carbine being increment one and the XM25 smart-munition weapon being increment two. The data is taken from Army R2 RDT&E budget justification sheets for each of the three years mentioned above.

Expectations as of FY 2000 (represented by the darkest boxes in **Table 6.2**, indicate that contract preparation was the first step in development, and was scheduled to last from the first to the third quarter of fiscal year 2000, shown on line 1 in **Table 6.2**. Similarly, milestone C for the combined OICW weapon was scheduled to begin in the fourth quarter of 2005 (line 8 in **Table 6.2**).

As of FY 2005, development had been split into the two increments to be developed concurrently. Milestone C for the XM8 was scheduled to occur in the first quarter of FY 2005 (line 12). Milestone B for the XM25 would occur at the same time (line 17). Milestone C for the XM25 would then occur in the second quarter of 2008 (line 20).

By FY 2007, major schedule slippage is obvious for the development program. Milestone B for the XM8 (line 9) is scheduled for the fourth quarter of FY 2007. Meanwhile, the XM8 milestone C has been pushed to the third quarter of FY 2008 (line 12). Thus, there is a fourteen-quarter – over three full years - slip in schedule between what was planned as of FY 2007 and what had been planned previously in FY 2005. Similarly, either technical difficulties or attention diverted to increment one of the system had resulted in significant schedule slippage for the XM25. Milestone B for the XM25 had been pushed back eleven quarters (line 17), with milestone C delayed eight quarters (line 20).

With the development effort for the OICW already lasting fourteen years, it is little wonder that the Army balked at continued development of a system that was missing major milestones by between two and three years.

Table 6.2 - Objective Individual Combat Weapon Yearly Schedule

Line	Objective Individual Combat Weapon	Fiscal Year	FY 2000				FY 2001				FY 2002				FY 2003				FY 2004				FY 2005				FY 2006				FY 2007				FY 2008				FY 2009				FY 2010			
		Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	Schedule Detail	System																																												
1	Contract Preparation	OICW	00	00	00																																									
2	Ammo/Fuze /Weapon/Fire Control Development				00	00	00	00	00	00	00	00							00	00	00	00																										
3	Quality Design & Build												00	00	00	00			00	00																										
4	Developmental Technical Testing																00	00	00	00	00																									
5	Developmental Operational Evaluation																					00	00	00	00																					
6	Live –fire testing																																													
7	Operational Testing ,(LUT/OT&E) & Assessment																																													
8	Milestone C																									00																				
9	Milestone B	XM8																																07												
10	Design & Fabricate																																	07	07											
11	Development Tests & Evaluation																																		07	07	07	07	07							
12	Milestone C																						05														07									
13	Engineering Changes based upon User Assessment																						05																							
14	Fabrication																							05	05																					
15	Production Verification Test																							05	05																					
16	Logistic Demo and IOT&E																								05	05																				
17	Milestone B	XM25																					05											07												
18	Final Design and Development / Fabrication																							05	05	05	05	05	05	05				07	07	07	07	07								
19	Test and Evaluation																														05	05	05	05	05				07	07	07	07	07			
20	Milestone C																																			05								07		

Legend:
2000 R2 - 00
2005 R2 - 05
2007 R2 - 07

Source: Army Budget Item Justification Sheets

Advanced Crew Served Weapon (ACSW)

The ACSW was similar to the previously discussed OICW, in that it was meant to combine a .50 caliber machine gun with a smart-munition firing capability. The system faced development problems and changes to program objectives that were similar to those experienced by the OICW as well and that also ultimately led to delay and cancelation. The ACSW was originally intended to provide only a smart-munition firing capability. However, the Army adopted a .50 Caliber machine gun variant, originally built to test design concepts by the weapon manufacturer, for development.[188] The ACSW program went forward as a dual-use weapon - a .50 Caliber machine gun that manually converted into a 25-millimeter smart-munition gun. In that configuration, the ACSW was meant to be the future replacement for both the M2 .50-Caliber machine gun and the MK19 grenade launcher.

As with the OICW, the introduction of the .50 Caliber capability into the system meant that the ACSW had to comply with two often contradictory requirements of weight reduction alongside the provision of a dual-use weapon with new electronic targeting components. The ACSW effort suffered because weight objectives made the system flimsy and unreliable.[189] However, with development ongoing for the ACSW and no other usable system scheduled for procurement in the immediate future, the Army faced the prospect of legacy M2 and MK19 systems wearing down from use in Iraq and Afghanistan.[190] Moreover, these legacy systems did not comply with the reductions in weight and increased transportability desired by the Army. As a result, the Army decided to shift focus away from the fully realized ACSW concept and to focus instead on developing the .50-Cal XM312, a variant of the ACSW which did not include the 25 mm smart-munition capability of the full ACSW system, but which could be upgraded to include that capability at a later date.[191]

The main problem with the XM312, however, was the low rate of fire of the system. Since the ACSW had originally been conceived of as firing smart-munition shells, it had been designed with a rate of fire of 260 rounds per minute.[192] As a .50-Caliber gun, this was considered too slow by evaluators, at about half the rate of the legacy M2 machine gun, so that the 'requirement creep' – defined as the introduction of requirements after initial phases of development have begun – associated with the introduction of the .50 Caliber requirement to the system was in direct contrast to what the system had been reasonably demonstrated as being able to do. As a result, significant technical risk existed within the development effort from the beginning. Moreover, even as developers had to struggle with these technical requirements, weight requirements introduced

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188 'General Dynamics 25 mm XM307 Advanced Crew-Served Weapon (ACSW)', Jane's (2010)
189 Rottman (2010)
190 Rottman (2010)
191 Rottman (2010)
192 'Too Good and Too Simple to Replace,' Strategy Page (n.d.)

additional complexity into the process. The use of a short barrel on the gun to achieve weight reductions led to a decrease in firing range for the ACSW in comparison to the M2.[193] Test firing of the weapon in 2005 thus proved disappointing, and the system was canceled in 2007.[194]

With the cancelation of the OICW and ACSW, a significant gap was left in the Army's long-term plans, given that these were the weapons meant to replace almost all of the legacy small arms then currently in use by the Army.

The other systems that were in development during FY 2006 are much less revolutionary. Three are meant to reduce weight as their sole or primary goal. Meanwhile, following cancelation of the ACSW, the Army also continued development of a lightweight .50 Caliber component of that system, now designated the XM806. Again, the primary goal of the system is weight reduction, not dramatic increases in lethality capabilities.[195]

Only the XM25, which attempts to preserve the smart-munition capability expected from the dual-ammunition OICW, appears to provide a novel lethality capability. **Figure 6.2** presents the Soldier Weapons Project Manager's weapon portfolio vision as of 2011. It essentially mirrors the content of **Figure 6.1** ten years earlier, and shows that the Army has not replaced the ACSW and OICW with anything equally ambitious in current or future development efforts. In the figure, the M240L is shown as an available weapon, and can be considered as a partial or full replacement of the M240B.[196] The XM806 may at one point partially or fully replace the M2 and M2A1 heavy machine guns, circled at the bottom of **Figure 6.2**. However, the OICW and ACSW systems were supposed to replace the M4, M16, M203, MK19, M50, M240B, and M249 as of 2001. No such grand plan is in place as of 2011, and with the lack of development of new systems, it appears that legacy small arms weapons must continue to be fielded for the foreseeable future. Not only does this mean that new capabilities are not available to soldiers in the field, it also raises concerns regarding the optimal operation and maintenance of aging small arms - that have their service life extended because of a lack of new weaponry - going forward.

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193 Rottman (2010)

194 Dates from Rottman (2010). Schedule data is sparse in the R2s for this system and is therefore not presented.

195 Nichols (2011)

196 Depending on cost, the M240L may not replace all M240B systems.

Figure 6.2 - Project Manager Soldier Weapons Mission (2011)

Source: US Army, Project Manager Soldier Weapons[197]

The ACSW and OICW efforts came with an opportunity cost of time and money, as can be seen in **Table 6.3**. Each program cost over $160 million, respectively. Both programs began in FY 1994 and lasted a total of fourteen years. [198] As with the longest-delayed anti-IED systems, it is the case here as well that scheduling delay may be the largest cost for these systems. Because of a focus on the most ambitious of systems, only in 2003 did work on the stand-alone smart-munition XM25 begin. Finally fielded for forward operational assessment in 2010[199], the XM25 performance has been described as follows:

[197] Nichols (2011)

[198] Start years for the OICW and ACSW, are from the following sources, respectively: 'Advanced Crew Served Weapon (ACSW),' Globalsecurity.org (n.d.) and 'Objective Individual Combat Weapon (OICW), FAS Military Analysis Network (n.d.)

[199] PEO Soldier Live (2010)

> 'No longer can the enemy shoot at American forces, then hide behind something,' said Brig. Gen. Peter Fuller of Program Executive Office Soldier. 'This is a revolutionary weapon. This is a game-changer.'[200]

Reports indicate the weapon has served its purpose in actual firefights, indicating a TRL of 9, a stage at which systems are 'fight proven' through successful use in missions.[201] The Army currently plans to procure the system.

It is true that much of the technology development that made the XM25 possible originated with the OICW and ACSW programs. Still, it might have made sense to cancel or suspend the OICW and ACSW programs much earlier in order to focus on bringing the stand-alone smart-munition capability to the field sooner given the urgent need for the weapon. This is especially true given that the weight-reduction and airburst-munition requirements were in such direct contradiction to one another. Planners at the beginning of the development process could have focused on the standalone XM25 capability as the true interim capability goal in **Figure 6.1**. From the start, the objectives would then have been developing and fielding the smart-munition capability and providing a near-term capability. Plans for further development could then include feedback from the field. Only then would attempts have been made to integrate and reduce weight in the overall system. If Army plans had been more flexible, it is possible that faster fielding of the XM25 could have reduced combat casualties in the field.

Aside from the canceled OICW and ACSW systems, each of the other development efforts from FY 2006 that are listed in **Table 6.1** has one or both of the following key features. One, objectives are relatively clear-cut. Two, the new system is derived from an older system. As a result, development generally costs less and takes less time, with a higher probability of success.

The M240L and Lightweight Machine Gun (LWMMG) programs exemplify these principles best. Both programs successfully produced potential replacements of the M240B. The sole purpose of the M240L program was to reduce weight compared to the M240B by incorporating titanium parts and utilizing novel manufacturing methods. The gun is 5.4 pounds lighter than the M240B at 21.8 pounds versus 27.2.[202] Development lasted seven years at a total cost of $4.9 million, and 5,987 M240L guns have already been procured as of FY2013.[203]

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[200] Army Times (2011)

[201] Department of the Army (2007)

[202] 'Equipment Piece of the Week: M240L 7.62mm Medium Machine Gun (Light)', US Army PEO Soldier (2012)

[203] Army Procurement P-1s, FY2011 to FY2013.

Table 6.3 - Yearly RDT&E Expenditures for Small Arms Systems

System Name	Fiscal Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	RDT&E Total	Total Years
OICW (XM8/XM25)	FY 1994	8.88	9.78	11.1	26.7	32.8	30.3	34.2	0	9.99	0.02							163.705	14
OCSW	FY 1994	5.46	6.59	11.9	14.6	3.17	11.3	27.3	33.7	30.7	17.1							161.941	14
XM109 Individual	--			0.92	0	0	4.01	3.37	0	0.76	0	0	0	0	0			9.049	9
XM109 Aggregate				0	1.06	0.84	0.94	2.23	3.17	0	0.52	0.66	0	0	0			9.409	
M240L	--			0.48	0.62	0.73	0.76	1.37	0.42	0.54								4.899	7
Lightweight Machine Gun	--					0	3.02	7.22	11.3	11.8	13	7.14	7.32	7.16	6.48	0	0	74.382	11
LWMMG	--							0	0	0	0.25							0.25	1
XM25 (Post-XM29)	--											12.5	5.38	7.28	23.5	36	34.4	119.1	6

Source: R-2 Budget Item Justification Sheets

Similarly, the Lightweight Medium Machine Gun (LWMMG) attempts to increase lethality and range when compared to the legacy M240B. The LWMMG utilizes a .338 caliber Norma Magnum cartridge, a larger caliber than the .50-cal bullet used in the M240B. This increases the effective range of the LWMMG over the M240B. The LWMMG is also around 3.2 pounds lighter than the M240B.[204] The weapon was largely developed without military funds 'in just over a year,' [205] and was initiated, independently of the Army, by a commercial manufacturer, suggesting that in cases of marginal technological improvement, there is scope for the Army to take advantage of vendor-funded development efforts. The system only appears in the R2s in one fiscal year, costing the Army a mere $250,000, total, in RDT&E funds.

As a result of the M240L and LWMMG development efforts, the Army has two very similar systems to choose between in filling a capability gap. In total, just over $5 million was spent in bringing the two options to the table.

The XM25 and Lightweight Machine Gun (LMG) are both new weapons, built from the ground up. Both introduce new types of ammunition to the battlefield. The XM25 uses the 25 mm smart-munition, while the LMG program introduces new types of lighter cased and caseless ammunition as part of the development process.[206] As a result, these programs are lengthier and more expensive. The XM25 resulted in costs of $119 million over six years, while funds spent on the LMG currently stands at $74 million over a nine-year period. Nevertheless, the objectives of both systems are clear and non-conflictive: fire a new type of ammunition in the case of the XM25, create a lighter gun in the case of the LMG. The XM25 appears poised to complete development in some form, while TRL level 7 tests for the LMG are ongoing as of May, 2012.[207]

The data suggest the obvious: the more complex development is, the more it costs, the longer it takes, and the more likely development is to result in cancelation as costs escalate and development is delayed. In order to minimize the likelihood of cancelation, it is important that requirements can be feasibly attained within the abilities of the development community. In the cases discussed here, it is recommended that development projects looking to reduce weight not be concurrently tasked with adding new complex technology capabilities to in-development weapon systems. Not only do competing requirements increase risk of cancelation, these cases suggest that schedule slippage can become particularly lengthy.

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[204] General Dynamics 'Lightweight Medium Machine Gun,' (2012)
[205] General Dynamics, 'General Dynamics Unveils New Medium-caliber Machine Gun at Joint Armaments Conference in Seattle' (2012)
[206] Phillips (2011)
[207] Phillips (2012)

Lessons Learned

While schedule delay and cancelation are not new findings in the system development literature, when looked at through the prism of portfolio management, they take on an added importance.

While the XM25 seems likely to salvage some of the smart-munition capability that the OICW and ACSW weapons were meant to provide, it is still the case that the cancelations of those two systems left a significant gap in lethality during both the Iraq and Afghanistan conflicts to this point that no other weapon could adequately fulfill.

In this portfolio, the costliest development efforts were also the most complex, provided the largest potential capabilities, and unfortunately were most prone to cancelation. Policymakers should be conscious that there may be no safety margin available for these types of systems, since it may be too expensive to allow for a concurrent, substitutable development effort. Portfolio managers should therefore be realistic in their initial expectations of such systems, and cautious when adding new requirements to these systems, so as not to increase technical risk that might lead to cancelation, and to allow timely fielding of at least the most important aspects of the capabilities desired from the system. In both the OICW and ACSW, integration of in-development components of the overall system was a problem that resulted in schedule delay, and ultimately cancelation in both cases. The technical problems experienced by both systems were largely a result of unrealistic and conflicting requirements in both cases, and the imposition of additional requirements following the initiation of development in the case of the ACSW.

While the OICW and ACSW were canceled, partial capabilities were salvaged from each. The XM25 arose from the OICW, while the XM806 continues weight reduction work begun under the ACSW effort. As a result, funding for the original development efforts was not completely wasted. However, it would behoove development managers to consider ways to get these important capabilities to the field sooner.

A portfolio view of systems also suggests the need for multiple, similar development efforts if development costs are not too high. At first glance, there would appear to be a high level of substitutability between some systems in the small arms portfolio. For example, the XM109 rifle performs much the same function as other sniper rifles, while the LWMMG provides subtle differences in capability when compared to the legacy M240 or the lightweight M240L. However, when considering these programs for termination in the context of the portfolio, one should take full consideration of the novel capabilities that these systems do provide. The XM109 and LWMMG, for example, both provide more lethality compared to .50-caliber weapons that might be very valuable in conflict against enemies with armored vehicles. However, in counter-insurgency, marginal increases in lethality against armored vehicles would only be a slight benefit not worth the price of development. Against a highly advanced enemy, on the other hand, such improvements may be important. Having these systems ready early means that when the need arises for these weapons, they are available and development does not have to be rushed to catch up to the situation on the ground. The systems can be put into production immediately, which increases lethality and potentially reduces casualties. Furthermore, in the case of systems such as the XM109 or LWMMG, there are potential cost savings associated with procuring and maintaining each system, if those costs are less than the legacy systems they replace, making development a good investment given the relatively low cost of RDT&E for each system. Finally, and perhaps most importantly, concurrent development of multiple similar systems provides a safety margin, within the portfolio context, if any individual development effort has a risk of failing performance and cost objectives.

Chapter Seven - Findings and Policy Recommendations

Policy recommendations related to the seventeen focus systems in the two fundamental capability portfolios are presented here. Further research inclusive of a larger number of systems across diverse fundamental capability portfolios will strengthen the conclusions reached.

The recognition that individual systems for development should be selected and managed in the framework of a portfolio so as to capture their interdependent and synergistic effects is an important concept within the system development and acquisition community.

Timely fielding of important capabilities should be an explicit goal of portfolio management. While it is tempting to eliminate several capability gaps at once by adding requirements to a key system, policy makers must consider whether doing so would increase development risk or delay the filling of urgent needs. Delay and cancelation resulted in a full decade without some important capabilities within the two fundamental capability portfolios examined here, and these should serve as cautionary tales for portfolio managers going forward.

Findings and recommendations, based on the two fundamental capability portfolios assessed here, are discussed below.

Finding 1: More expensive systems are canceled more frequently

Relatively more complex, costly development projects were expected to provide the largest capabilities within the two fundamental capability portfolios, but they were also the most likely to be canceled or experience significant delays in schedule. In the anti-IED portfolio, ASTAMIDS, providing a unique standoff capability, has been in development for nearly two decades and is delayed by about thirteen years, while the GSTAMIDS program never resulted in a standoff mine-detection UGV capability. The OICW and ACSW were to provide lighter weight with improved lethality in small arms, but both were canceled.

It may come as no surprise that complex systems providing 'leap-ahead' capabilities are also the most likely to experience problems in development or escalating expected procurement costs.

Finding 2: Technology is commonly salvaged from canceled systems

Of the seventeen systems reviewed here, four were officially canceled – these were the OICW, ACSW, GSTAMIDS, and Mongoose. In each case, some portion of the technology was transferred to another development effort and in most cases resulted in fielding, so that cancelation is not synonymous with total failure.

The OICW resulted in the XM25 gun and air-bursting munition, which appear to be on the brink of fielding. The ACSW transitioned into the development of a lighter-weight .50 caliber crew-served weapon. The GSTAMIDS program was able to produce an effective close-in ground penetrating radar currently in use during anti-IED operations, and the Mongoose shape-charge was included in the GSTAMIDS program in hopes of providing a mine neutralization capability, although that program was in turn canceled. Still, there is evidence that program cancelation, in general, is not a total loss.

Recommendations for individual system development

Recommendation 1: Fielding useful, timely systems unburdened with excessive requirements should be the goal

In this research, development efforts with focused goals were more likely to succeed in producing fielded systems. In such cases, timely fielding can be followed by further development to introduce improved or new capabilities to the system once lessons learned from real-world use are incorporated into further development. This strategy of fielding would provide a higher probability of success for system development and result in timelier fielding of important capabilities. Indeed, the Army has been effectively engaged in this strategy when new systems are salvaged from canceled development efforts, but it is inefficient and not timely to develop complex, high-requirement systems, scale those efforts back after complications, and then field a lower-capability system after an extended period of time.

It is important for the Army to field systems when they are needed, and not wait for ideal systems that can do everything that will eventually be asked of them. The various iterations of the Shortstop / Warlock / CREW jamming systems are an example of this principle, because they brought immediate and vital capabilities to the field at the time that they were actually needed. However, rapid development and acquisition cannot be the sole source of such systems. In addition, the Army needs to anticipate capability gaps as much as it can and fund solutions through traditional RDT&E, not only to meet these anticipated gaps in a timely manner, but also to equip the Army with flexible technologies and systems to be quickly adapted to meet unexpected future threats.

Recommendation 2: Realistic and simple initial requirements are highly desirable

In many of the cases studied, requirements were clearly too optimistic. **Table 7.1** presents the systems that exhibited attributes hindering successful development. These systems are ordered from most expensive systems at the top to least expensive, in terms of RDT&E dollars spent. The familiar color-coding scheme is used, with red systems terminated, yellow systems still in development, green systems procured, and blue systems not yet procured following the conclusion of development. The second column of the table indicates the systems for which multiple requirements were a problem.

Table 7.1 - Development Hindrances in the Fundamental Capability Portfolios

System Name	Problematic Requirements / Requirement Creep	Within System Integration of under-development components	Integration with other under-development systems
ASTAMIDS	Yes	Yes	Yes
GSTAMIDS	Yes	No	Yes
OICW	Yes	Yes	No
ACSW	Yes	Yes	No

The OICW and ACSW programs were both supposed to provide new lethality capabilities at system weights that were below those of legacy systems. In reality, it would be a huge challenge just to provide small arms that fired two types of ammunition in the field, let alone under a weight requirement, given the complications inherent in the development process. In the case of GSTAMIDS, requirements to mask the system from enemy detection, equal speed between backward and forward driving, combat-ready GPS, and hardened military components were all added FCS requirements that delayed the fielding of a standoff detection capability. While high requirements are important in the long run, it is likely not the first priority in anti-IED missions in Iraq and Afghanistan. Maintaining such high requirements only delays the fielding of a usable system.

Recommendation 3: The use of COTS/GOTS components and systems should be a focus

As stated above, expectations and requirements for GSTAMIDS were lofty. Moreover, development of the Autonomous Navigation System, a component of GSTAMIDS, had requirements that likely necessitated a traditional, from-the-ground up research and development effort to achieve them. If the requirements were reduced, alternative COTS and GOTS navigation systems might have been suitable components for GSTAMIDS instead. The development of the AMDS exemplifies the use of GOTS components well, and while the AMDS may not provide all of the capabilities expected from

GSTAMIDS, development appears to be much smoother and faster. The rapid fielding of the FIDO/Packbot provides another example of the successful use of off-the-shelf technology. The FIDO/Packbot integration effort had simple requirements of remote explosive detection, and was fielded in a usable form with future options for system upgrade.

Recommendation 4: The Army should refrain from 'requirement creep'

Under austere budgets, policymakers might single out a system already under development for another purpose, and decide that it could close a capability gap by adding new requirements to the system. Such an approach could be a mistake. This occurred in the case of ASTAMIDS, where target identification requirements were added to expected mine detection capabilities. 'Requirement creep' of this kind needs to be weighed carefully given the risk added to an already complex development project, cost-growth that is likely to be associated with it, schedule delay as fielding is pushed further and further down the road, and finally the Army's poor historical record in successfully adding requirements to systems already under-development.

Rather than start with lofty expectations that increase over time, the Army should start with simple requirements that lead to fielded systems. A development effort that exemplifies this recommendation is the lightweight machine gun, which seeks solely to reduce weight over legacy machine guns. While development has been lengthy, it appears that a fielded system, which provides a needed capability, will result from it.

Recommendation 5: Within systems, integration of in-development components should be minimal

While this recommendation largely arises from the OICW, integration of concurrently in-development components was also an issue for ASTAMIDS and the ACSW, as indicated by the third column of Table 7.1. The recommendation is likely to apply to other complex systems as well, and is revisited below in relation to portfolios of weapons.

In the case of the OICW, several important components of the overall system were still in early stages of development even as integration of those components had to occur in order to remain on schedule. In particular, there were issues with the effectiveness of the blast provided by the 25mm air-bursting munition. If the shape or size of the round itself had to be changed, it would delay development of the main small arm system and potentially violate weight requirements. On the other hand, if changes to the small arm could not have been made, it would mean requiring increased burst for the 25mm munition at a fixed size, again causing risk of cancelation and delay.

Turning to GSTAMIDS and ASTAMIDS, based upon the pattern of development carried out under FCS development program, it seems as if the Army considered all the capability gaps that existed across multiple capability areas and attempted to fulfill all of them, for the foreseeable future, in one fell swoop. The false hope was that manufacturing would be cheap because of common chassis amongst vehicles, while munitions would be common across cannons. Also, vehicles would be light and transportable, while communications would extend to every echelon of the blue force.

One of the major problems with the FCS vision was that the military did not foresee the huge problems of integration inherent in the co-development of so many systems at once. As indicated in column four of Table 7.1, this was a problem in the case of GSTAMIDS and ASTAMIDS, as requirements kept changing based on what was needed by another branch of the FCS, or based on the technical or weight requirements of another in-development system. These problems ultimately led to significant cost growth and delay in the case of GSTAMIDS, and delay if not documented cost growth in the case of ASTAMIDS.

The Army needs to learn from this lesson going forward. In performing expected capability calculations in the future, policymakers need to be cognizant that co-development and integration between dependent systems increases risk markedly. Integration is best carried out when the technologies in separate systems are already matured, as exemplified by the FIDO/Packbot effort.

Recommendations for portfolio management

Recommendation 1: Given the inevitability of failure in some development programs, portfolio management must explicitly develop alternative plans.

Given that ambitious systems are delayed or canceled at higher rates than other systems, but given that useful technology can be salvaged from such programs, the Army should consider alternative plans that initiate immediately in cases where no fielded systems seem likely to arise from current development efforts.

In the past, the Army was left scrambling with the cancelation of the OICW and ACSW and was slow to react to warning signs from both programs. As a result, the Army continually anticipated the fielding of those systems and was late in making alternative plans when they were canceled. In those cases, development on the standalone XM25 air-bursting grenade launcher and XM806 lightweight .50 caliber crew-served gun could have begun much sooner when the ambitious systems failed to meet objectives and seemed destined for schedule slippage, and indeed likely should have been the first step in development from the beginning. Schedule slippage and technical problems in ambitious systems need to be taken very seriously in the future, and need to trigger the immediate implementation of alternative plans. In a tight budgetary environment, this may mean that development of the ambitious system is halted so as to fund systems providing a lower capability but a higher likelihood of near-term deployment. Halting the program not only allows funds to be diverted to more important immediate usage, but also incentivizes developers to stick to the established schedule. In the case of the standoff mine detection systems, this might have meant halting the ASTAMIDS and GSTAMIDS programs, providing a larger commitment to the training of bomb-sniffing dogs, advertising the development program as being open to COTS solutions, or development of systems such as the Change Detection Workstation and procurement of more UAVs to provide surveillance. While these avenues are only partial substitutes for automated standoff detection, it would at least fill some part of the capability gap that otherwise would remain open while waiting for the development of an ideal system.

In fact, one possible avenue in performing a portfolio review is a two-stage analysis. The Army could identify at-risk development projects based on historical data, remove those programs from the portfolio analysis altogether, and assess whether capability gaps can all be filled with 'very likely to succeed' development efforts. This would provide the Army with a do-able 'threshold' requirement level, which the Army should expect from development efforts. Adding the high-risk development projects back in would result in an 'objective' requirement level that the Army would ideally like to attain. Performing portfolio analyses in this way would allow the Army to have a clear backup plan in the event of cancelations in the portfolio.

Recommendation 2: In choosing systems to develop, the Army should explicitly consider time to fielding and the risk of program failure of each system, and should attempt to fulfill capability gaps sooner rather than later.

A naïve analysis of alternatives without considering risk could have an adverse effect if systems that look like they will provide a large contribution to one or a variety of capability gaps are valued without considering the risk of program delay and failure.

In comparing the OICW and XM25, a simplistic analysis would note that the OICW completely subsumes the capabilities provided by the XM25. Indeed, the XM25 development effort would simply be cut since it is 'redundant.' Yet, the XM25 was the system ultimately fielded to provide the required air-bursting lethality.

Such a simplistic view does not take into account the fact that capability provision may be unrealistic, as was the case with the OICW. It does not take into account historically poor records on completion timeframe, as exemplified by the decade-plus efforts associated with the OICW, ACSW, GSTAMIDS, and ASTAMIDS. Finally, this naïve view does not take into account that lack of fielded sub-components in major development efforts creates current capability gaps for soldiers in the field, as exemplified by the lack of standoff detection in ASTAMIDS amongst other examples.

In order to properly assess how useful a development project is, the Army should assess the expected capability of the system, discounted for length of development and likelihood of program failure, prior to considering overall funding decisions. Engaging in these calculations could result in better decisions; for example, funding the FIDO/Packbot, which provides a 'just enough' detection capability without the autonomous navigation and high navigation speeds that were lofty requirements of GSTAMIDS.

Recommendation 3: Redundancy, rather than being a problem, may be a necessity

In the two fundamental capability portfolios reviewed thus far, there was little evidence of wasteful spending on redundant development efforts. In the case of small arms, 'redundant' systems – those that performed essentially the same function as another fielded or in-development system - were cheap or essentially free. Thus, in the consideration of eliminating redundancy, one needs to also consider the cost of developing a redundant system. As systems are rarely perfectly substitutable, there is more room for redundancy if the development programs for the systems are cheap. The LWMMG (a medium caliber machine gun) was developed under the initiative of a private firm, and $250,000 of military funding was used for evaluation purposes. The XM109 sniper rifle was also cheap, at only $9 million in development funds. The anti-IED systems mirror this situation almost exactly. The Scanjack Mine Sweeper required $960,000 for evaluation, while the EDIT handheld mine detector was developed for $6.443 million.

In all four of these cases, the Army was given one more option to fulfill a capability at very low cost. It should also be noted that each of these systems provides a slightly different capability than the comparison system – for example, the LWMMG provides a larger caliber bullet than the M240, while the EDIT unit provides a better imaging capability than similar handheld detectors. In each case, it is cheap enough to pursue more than one system to guard against the failure of any one developing system as well as potentially acquire an added capability.

No example illustrates this point better, however, than the IED jamming systems developed for use against insurgencies in Iraq and Afghanistan. While lack of coordination and collaboration between organizations and services can be rightly criticized, it is still the case that concurrent development of several jammers resulted in quick fielding of solutions that were urgently needed. Restricting the number of jammers under development might have reduced the chances of producing an effective jamming capability in a timely manner. System development is often only duplicative on the surface. The Warlock Green and Red were both jamming devices, but both were needed to counter IEDs triggered by different radio signal frequencies.

While budget cuts create an aversion to 'redundancy' and a motivation to trim the fat from development portfolios, the Army needs to be careful not to cut too close to the bone. In the case of relatively simple, historically successful development efforts, such as minor upgrades to existing systems, it makes little sense to provide two substitutable development programs to accomplish the task.

Producing separate systems without common standards that impair interoperability between the services and thus require wasteful system refinements should also be avoided. However, in the case of complex, highly ambitious and risky programs, or where an important capability gap needs to be fielded quickly in response to rapidly evolving threats, the need to reduce expenditures should be tempered by the need for a safety margin. In these cases, development of multiple initial technologies, competition in prototyping, and competition at development milestones may result in quicker fielding, reduced procurement, operation and maintenance costs, and potentially result in a higher-capability system. Trimming the technology options too much initially and relying on one development effort to produce a multitude of capability improvements might lead to cost-growth, delay, and long-term capability gaps in the event of program failure.

Wisely, the Institute of Land Warfare recently discussed portfolio reviews in terms of "validating, modifying, or recommending termination of *requirements* driving capability development" (emphasis added).[208] This philosophy of focusing attention at the requirements level in portfolio analysis and providing the correct number of system development efforts to meet those requirements should be maintained going forward.

[208] Institute of Land Warfare (2010)

Appendix A

One hundred and four unique, named systems were identified as belonging to either the Force Protection or Lethality Force Operating Capabilities within the fiscal year 2006 R2 RDT&E financial documents provided by the Army.

The fiscal year 2006 R2 RDT&E financial documents provided by the Army are split between two types of development efforts: those related to systems, and those related to functions.

Some systems are clearly and consistently named, and funds for these systems can be tracked across subsequent fiscal year R2s. Such systems are also defined and discussed in other military and non-military sources. The systems are listed in the tables below.

Other entries in the R2s appear to be systems, but cannot be verified from other sources. Examples of this type of system are the Future Combat System (FCS) Standoff Mine Detection System and the Long Range Aviation Missile. The FCS Standoff Mine Detection System is listed across multiple R2s in successive fiscal years as a system in its own right.[209] However, there is little reference to the system in other sources, and it is likely, in actuality, to be a funding stream for the Ground Standoff Mine Detection System (GSTAMIDS). The Long Range Aviation Missile appears only in the FY 2006 R2 as a 'one year congressional add', indicating that it is not expected to be a regularly funded program, which would span over multiple years. No other sources give any indication of funding, development, fielding, or even a basic description for this system, however. Since, as stated previously, the FCS Standoff Mine Detection System is very likely to be GSTAMIDS under another name, it is not listed below. However, as there is no evidence that the Long Range Aviation Missile is not a unique system, it is included in the table for lethality.

Functions are often funded at relatively advanced stages of development, but cannot be identified as individual systems. Countermine 'lightweight appliques and structures' are funded at the advanced technology development stage (6.3), and are likely to be used in active protection or armor systems for one or more types of vehicles.[210] However, the technology is never explicitly stated to be a system in its own right, or a component of a system. The technology is therefore not listed in the tables below.

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[209] See, for example: http://www.dtic.mil/descriptivesum/Y2007/Army/0603606A.pdf

[210] The relevant R2 is: http://www.dtic.mil/descriptivesum/Y2006/Army/0603005A.pdf

Force Protection

Function	System Name
Active Protection / Threat Detection	AN/APR-39A (V)1 Radar Warning Receiver
	Active Protection System[211]
	Close-In Active Protection System
	Suite of Radio Frequency Countermeasures Radar Warning Receiver
Air Defense	Future Army Attack and Missile Defense System
	Joint Land Attack Cruise Air Defense Elevated Netted Sensor
	Low Cost Interceptor
	Medium Extended Air Defense System
	Patriot Advanced Capability
	Mobile Tactical High Energy Laser
	Surface Launched Advanced Medium Range Air-To-Air Missile
Anti-IED	Airborne Standoff Minefield Detection System
	Autonomous Mine Detection Sensors
	Change Detection Workstation
	EDIT Advanced Landmine Detection
	Explosive Standoff Minefield Clearer (Mongoose)
	Ground Standoff Mine Detection System Future Combat Systems
	Husky Mine Detection System
	ScanEagle
	SCANJACK Mine Clearing System
	Shortstop Electronic Protection System
Armor (Soldier-borne)	Fully Integrated Combat Helmet
Armor (Vehicle-borne)	Abrams Reactive Armor Tiles
	HMMWV Frag Kits 5/6, Add on Armor Kits
Blue Force Tracking	Ground Combat Identification
	Individual Combat Identification System
	Portable Emergency Broadband System
Camouflage	Ultra Lightweight Camouflage Net System
Gunshot Detection	Overwatch
Launch Detection	All Weather Radio Frequency (RF) Launch Detection
	Enhanced AN/TPQ 36 Radar
	Joint Tactical Ground Station
	Lightweight Counter-Mortar Radar
Nuclear Detection	Eagle Eyes Nuclear Detection
Shelter	Lightweight Rapidly Deployable Hardened Shelters
Surveillance	Cerberus Sensor Suite Program
	Close Surveillance Support System
	Sentinel
	Unattended Ground Sensors
Uniforms and Clothing	Advanced Bomb Suit

[211] This was an active protection system associated with the Future Combat System, but was never given a unique name or designation. See: http://www.fas.org/sgp/crs/weapons/R41597.pdf and http://www.federalnewsradio.com/?nid=&sid=1703054 for discussions of the characteristics of this system and its eventual cancelation.

	Air Warrior
	Army Combat Uniform
	Chemical Protective Ensemble
	Modular Boot System
	Suit Contamination Avoidance Liquid Protective
Weapon / Insurgent Detection	PING Wideband RF Target ID Systems
	Suite of Sense Through the Wall (STTW) Systems for the Future Force

Lethality

Function	System Name
Accuracy	Meteorological Measuring Set-Profiler
Aircraft	Armed Reconnaissance Helicopter
	Black Hawk Modernization
Artillery	Electromagnetic Gun
	Lightweight 155 mm Howitzer
	Multiple Launch Rocket System HIMARS
	Non-Line of Site XM1203
	Solid-State Laser Weapon
Ground Vehicles	All-Composite Military Vehicle
	Future Tactical Truck System
	Ground Combat Vehicle
	Mounted Combat System XM1202
	Stryker Vehicles
Land Mines / Detonation Systems	Intelligent Munitions System
	Magneto Inductive Remote Activation Munition System
	Spider
Laser Designator / Range Finder	Lightweight Laser Designation Rangefinder
	Small Tactical Optical Rifle Mounted (STORM) micro-Laser Range Finder
Missiles	Advanced Multi-Mission Precision Guided Munition
	Advanced Precision Kill Weapon System
	Common Smart Submunition
	Compact Kinetic Energy Missile
	Guided Multiple Launch Rocket System
	Joint Common Missile
	Line-of-Sight Anti-Tank Missile
	Loitering Attack Missile
	Long Range Aviation Missile
	Mid-Range Munition
	Precision Attack Missile
	XM982 Projectile
Mortar Rounds / Mortar Systems	Mortar Anti-Personnel Anti-Material XM1061
	Precision Guided Mortar Munition
	Lightweight Dismounted 81 MM Mortar System
	Objective Non-Line Of Sight (NLOS) Mortar Technology
Small Arms	.338 Norma Magnum Lightweight Medium Machine Gun (LWMMG)
	Advanced Crew Served Weapon (ACSW)
	Anti-Material Payload Rifle (XM109)

	Counter Defilade Target Engagement System (XM25)
	Objective Individual Combat Weapon (OICW)
	Lightweight Machine Gun (LMG)
	M240L
Targeting / Queuing	Advanced Field Artillery Tactical Data System
	Fire Control-Node Engagement Technology
	Improved Position Azimuth Determining System
	Paladin Digital Fire Control System
	Target Acquisition Sensor Suite (BRITE star II)
	Phoenix Battlefield Sensor System
Unmanned Aerial Vehicle	A-160 Hummingbird
	Excalibur Tactical Unmanned Combat Air Vehicle
	Long Range Advanced Scout Surveillance System
Unmanned Ground Vehicle	Talon
	Special Weapons Observation Reconnaissance Detection System (SWORDS)
Vision / Weapon Sights	AN/PVS-6
	AN/PVS-7
	Fused Multi-Spectral Weapon Sight
	Head Tracked Sensor Suite
	Soldier Mobility and Rifle Targeting System

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